THE SIXTIES

A CHALLENGE TO INDUSTRIAL ENGINEERING

11th ANNUAL AIIE CONFERENCE PROCEEDINGS MANUAL

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Foreword

This year marks the beginning of a new decade. The previous decade saw the National Industrial Engineering Conference grow from an infant to the nations leading forum of industrial engineering. Much was done in those ten years in the way of research and advancement for the profession. The program this year marks the way for the growth that is still to come.

We are pleased to present herein a complete printing of the speeches and papers presented at the 1960 National Conference of the American Institute of Industrial Engineers. A table of contents is included for your convenience.

Your committee for this conference wishes to express their thanks and appreciation to all those who have presented papers and to all others whose participation has contributed to the success of the conference.

Roy L. Coleman,
Director of Proceedings

The Sixties - A Challenge

Progress in this decade will have the acceleration of a rocket. Research will bring us new ideas, new techniques, and the demand for yet more research. We must be alive to the trends in the mathematical, physical, and social sciences if our individual professional development is to keep pace with the times. To this purpose is dedicated the ELEVENTH ANNUAL NATIONAL CONFERENCE and CONVENTION of the AMERICAN INSTITUTE of INDUSTRIAL ENGINEERS.

Purposes of the AIIE

The AIIE *is dedicated to the following purposes:*

To maintain the practice of Industrial Engineering on a professional status

To foster a high degree of integrity among the members of the industrial engineering profession

To encourage and assist education among members of the profession

To promote the interchange of ideas and information among members of the profession

To serve in the public interest by identification of men qualified to practice as Industrial Engineers

To promote professional registration of Industrial Engineers.

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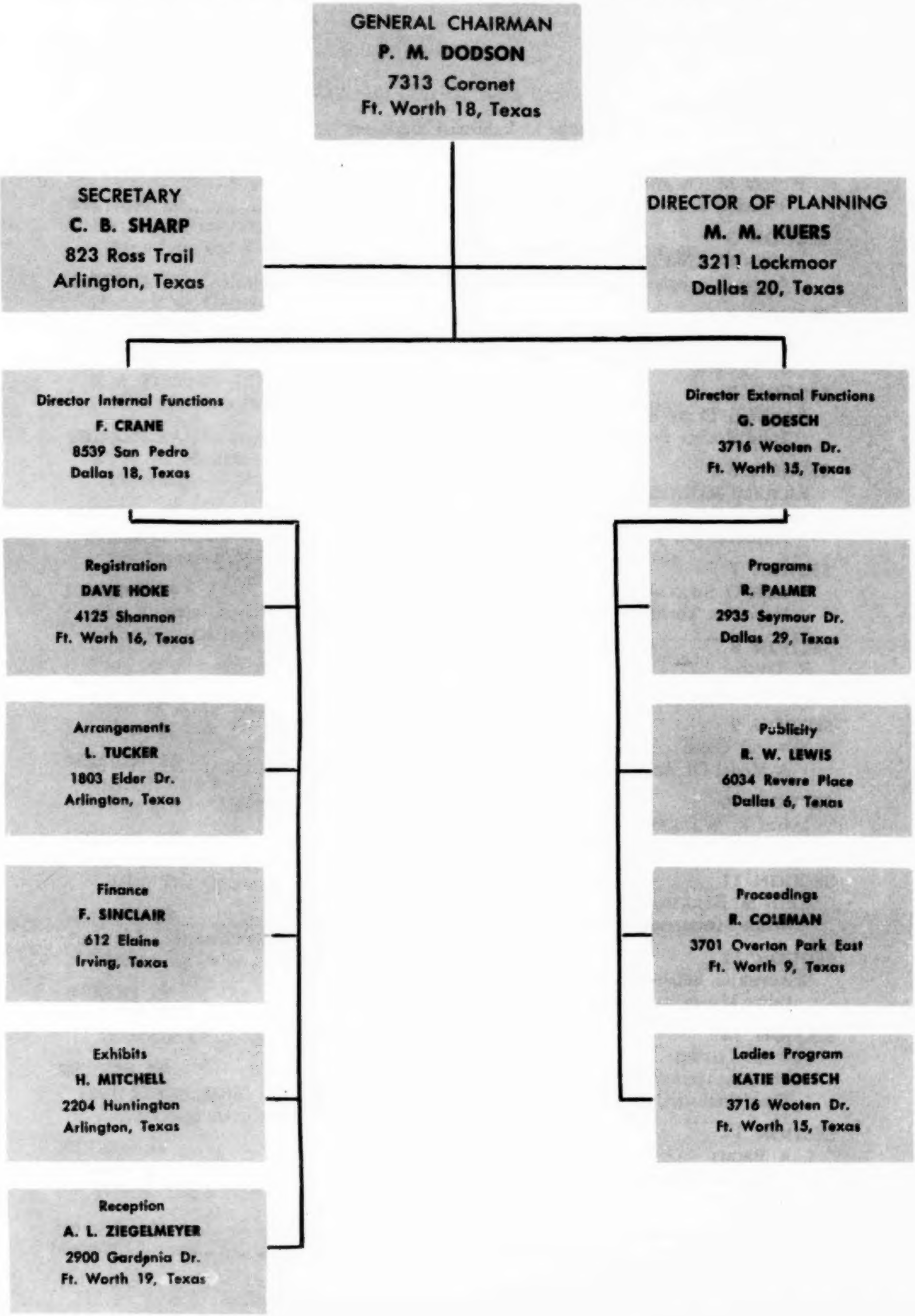

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INDEX

SECTION 1
FRANK JOHNSON
The Sixties — A Challenge to Industrial Engineers 15

SECTION 2
HENRY M. OWADES
Practical Industrial Engineering Research Applications 21

SECTION 3
JOSEPH D. CARRABINO
Some Proposals For A Unified Program of Management Controls 27

SECTION 4
THOMAS C. FISHER
Total System Concept — Bell Helicopter 33

SECTION 5
RAOUL S. DOBYNS
Solid Rocket Production — A Look To The Future 51

SECTION 6
RICHARD MUTHER
Systematic Layout Planning — A Patterned Approach To Plant Layout Procedure 63

SECTION 7
RALPH O. SWALM
How Not To Make Equipment Replacement Decisions 71

SECTION 8
K. LIFSON
Work Sampling 77

SECTION 9
BURTON GRAD
A Model Of An Elementary Industrial Processing System 81

SECTION 10
JAMES R. WALKER
Control of Machine Member Position, Discrete vs. Continuous 89

SECTION 11
JOHN M. BARKSDALE
Work Measurement & Methods In The Process Industry 97

SECTION 12
WALTER G. SEINSHEIMER
Labor-Management Problems 99

SECTION 13
EDWARD LUFTIG
The Managerial Problems of Industry And Their Industrial Engineering Implications 107

SECTION 14
L. R. BECHT
Improved Government Through Industrial Engineering 113

SECTION 15
HAROLD O. DAVIDSON
The Next Decade In Operations Research 121

SECTION 16
DALE JONES
Fair Day's Work Times 127

SECTION 17
SERGE A. BIRN
Master Clerical Data — Clerical Controls With Economy 135

SECTION 18
T. K. KOLNER
An Airline Spare Parts Problem 141

SECTION 19
NYLES V. REINFELD
New Uses and Practical Applications of Mathematical Programming 147

SECTION 20
HAROLD W. GEORGE
Scheduling and Control 155

SECTION 21
R. A. FULLER
New Horizons In Design Operations For Tomorrow's Engineering 161

SECTION 22
W. H. M. MORRIS
Physiology — Physical Input vs. Physical Output 173

SECTION 23
ROGER L. SISSON
An Appraisal Of The Status of Research On Production Scheduling 185

SECTION 24
J. M. BROWN
The Role Of Industrial Engineering Research In Industry 187

SECTION 25
JOHN M. ALLDERIGE
An Appraisal Of Work Measurement Research 189

SECTION 26
ALAN J. ROWE
Research In The Design Of Control Systems 199

SECTION 27
Chief Industrial Engineers' Symposium — Session 1
What The Operating Departments Expect From Industrial Engineering 209

SECTION 28
Chief Industrial Engineers' Symposium — Session 2
Measuring Industrial Engineering Performance 213

SECTION 29
ARTHUR A. SMITH
Economic Challenges In The Sixties 215

SECTION 30
JOHN D. COLEMAN
Engineering Astigmatism 217

SECTION 31
JAMES Q. DU PONT
Pattern For Success 223

Senior Chapters 227
Student Chapters 229

KEYNOTE ADDRESS

by **FRANK JOHNSON**
President

AMERICAN INSTITUTE OF INDUSTRIAL ENGINEERS

Mr. Johnson graduated with honors from North Carolina State College with a degree in Civil Engineering. He expanded his knowledge of Engineering with graduate work in Industrial Engineering.

At the present time, Mr. Johnson is Manager, Production Engineering Design Analysis at the Lockheed Aircraft Corporation in Marietta, Georgia, is a director and assistant to the President. Prior to his present positions, he has had experience as production Supervisor and Quality Control with manufacturing concerns. He has also served as head of Industrial Engineering Department at Southern College. Because of his energy and enthusiasm, Mr. Johnson is well known in business and professional organizations. He has served as Pesident of the Atlanta Management Club, Atlanta Tipoff Club, President of the Atlanta chapter of A I I E, Lockheed Management Club and the Atlanta Personnel Club. Being a Registered Professional Engineer, he is also a member of the National Society of Professional Engineers.

THE SIXTIES — A CHALLENGE TO INDUSTRIAL ENGINEERING

by FRANK J. JOHNSON

Manager, Production Engineering Design Analysis, Lockheed Aircraft Corporation

I WOULD like to add my welcome to all registrants to this 11th Annual National Conference of the American Institute of Industrial Engineers.

Last year in his keynote address, Past-President George Gustat discussed the expanding horizons of our profession. He defined a horizon as a limit of perception or experience. A problem for which you do not know the solution, is, of course, always beyond that point. As one of these problems is solved, our horizon is pushed back or expanded until we can see more and more into the future. I felt that it would be appropriate for a "Keynote" address to take a look into this future, as best we can to see the challenges facing our profession during the decade we are now entering. Before we can look ahead, it would seem appropriate that we glance back for a moment to see from whence we came.

A study of history reveals that the engineering profession probably started in the days of the Roman Empire when such projects as roads, bridges and aqueducts were designed and built, usually for the use of the armies. Between military campaigns there was time to perform the same functions for the civilian population. I guess we could say that civil engineering was the only form of engineering until about midway in the 19th century.

In 1852, when the ASCE was organized, there was but one national engineering society in the United States. Less than thirty years later, splintering began, starting with the mining, mechanical and electrical branches. This has continued until there are now some 70 engineering associations with widely varying objectives, qualifications for membership and accomplishments.

The great majority of these branches bear a name that is descriptive with the type of work performed. For instance, we would all recognize the field covered by electrical, chemical, radio, ceramic and mining engineers to name a few. Industrial engineers are not so fortunate. In fact we have spent considerable thought and time in developing a definition of industrial engineering for our own people as well as for the general public. The many suggested versions we received illustrates the basic problem we have within our own family. Compounding the problem is the rapid and constantly expanding scope of functions and techniques falling within the industrial engineer's sphere of influence. New fields of industrial engineering are developing so rapidly, that graduates more than three years out of school are often out of touch with the latest developments in the "state of the art."

In many ways the young engineer who has received training in the newest techniques and practices of his profession, has a distinct advantage over those of us who must strive to catch up with a rapidly advancing profession. The day of the "stop watch" engineer has passed.

These same young engineers, however, have many new problems facing them as we move ahead into the Sixties. Unfortunately there has developed a trend toward collectivism, particularly as it applies to the employer-employee relationship. Of all the professions, engineering has the most members of labor unions. This trend has been the cause of some concern because society and technology have not only utilized the professional competence of the engineer, but they look to him to supply managerial and executive ability as well. Today, more than ever, the engineer must possess the technical and intellectual discernment to anticipate problems and solve them almost before others think of them. Inevitably, engineers make policy in a host of industries and vast government agencies which 10 or 20 years ago looked to the corporation lawyer, the financier, or a political figure for the lead. Just as inevitably in a period when the battle between freedom and totalitarianism is being waged, national policy must be drafted with the aid of engineers.

It would thus appear to me that the young engineer would do well to develop traits of leadership and the ability to accept responsibility if he intends to develop in professional stature. This would be difficult, if not impossible, if he remains satisfied to be subject to the leveling influence of a bargaining agency who will "represent" him in all aspects of his work relationships.

We constantly hear about the need for doing something for the "common man." Perhaps we would all be better off if we had more "uncommon" men—like Edison, Einstein, Benjamin Franklin and Henry Ford. People like this as well as many others in all fields of engineering, science and management have contributed greatly to the tremendous increase in productivity that has given our nation the highest standard of living ever known. There is only one way to continue to improve our standard of living and that is to increase productivity. While a lot of people contribute to this, it is well to remember that increasing the productivity is the industrial engineer's chief responsibility. This is recognized by many foreign technicians who came to our country seeking out the reasons for our so-called production "know-how". They visit our universities and seek out the Industrial Engineering Department and do likewise when visiting our industrial plants.

This recognition has been one of the main factors in the "explosive" growth of our profession. In the eleven years since A. I. I. E. was founded we have grown to a society of almost 10,000 members. In addition we have almost 2000 student members and 600 affiliates. These members are served by 104 senior chapters and 45 student chapters. More important, our growth continues at a phenomenal pace. We increase ourselves by 25% each year while creating chapters in from 10-12 new communities each year.

In addition to this astounding record, the attendance and enthusiasm at our chapter, regional and national conferences continue to be the envy of all other societies. This can be contributed, in part, to the predominance of young members in our Institute. This is to be expected in a profession that itself is relatively young. All of this has resulted in recognition by other societies and the general public. One evidence of this is the recognition by the Engineers Joint Council who only last year gave us the full status of a regular member. This recognition will continue to increase our professional status and prestige—if, we continue to demonstrate our ability to accept our professional responsibilities.

Our Long Range Planning Committee is charged with the responsibility of anticipating future problems and taking the necessary action to do something about increasing this recognition. I am happy to report that considerable progress is being made by our national organization in presenting our "professional face" to the public.

Of course the chapters and individual members present this "face" to the local community. It is to be expected that a person will judge the industrial engineering profession by the industrial engineers he happens to know. This is why it is so important for each engineer to develop him professionally as best he can. I like to compare our profession in some ways with the medical profession. For example, if a young doctor graduated, hung out his shingle and opened up a practice, he would progress normally for awhile. However, if he did not attend symposiums and conferences or study his medical journals, he would soon be so far behind in the state of the art that he would begin to lose his patients, literally and figuratively. He would be trying to treat diseases he never heard of and without the benefit of drugs and medicines that had been developed since he obtained his MD degree. The same thing happens in our profession. The engineer who has not attended a conference or symposium or who has not kept up with the latest techniques of industrial engineering as published in books and in our own JOURNAL, will soon become an obsolete engineer. The industrial engineering profession is moving rapidly into new fields, such as automation, data processing techniques, regression analysis and other mathematical tools proven successful in work design.

When someone tells me our JOURNAL is too technical and he can't read the articles, my first impression is that there is a man whose profession has left him behind. This, of course, does not preclude the desirability of publishing more articles of a practical nature. The proper blend is something our JOURNAL staff is striving to attain.

In my visits to many chapters around the country I have had the opportunity and privilege of talking with many of our members. Perhaps the most frequent question asked me is, "What is the A. I. I. E. doing to increase our professional status and prestige?" The answer lies partially in the fine work of our many committees serving in the areas of professional development, professional relations, research, international relations, long range planning and many other equally important functions. However, I am convinced that true prestige and status will come more rapidly with recognition of ability. As each engineer develops himself professionally where he can perform a real service, he will then receive the rewards that go with recognition of ability. A successful industrial engineer creates a demand for others like him. As the demand increases, all will partake of the benefits.

So much for where we are and whence we came. Let's, for a moment, look into the future and see the challenges that face us during the decade of the sixties. In my opinion, we will continue to see a rapid growth in the engineering profession and in our particular branch especially.

At present some 650,000 engineers are classified as such by the U. S. Census Bureau. The number of engineers is increasing at a rate of from two to five times that of the population as a whole. We are currently graduating about 40,000 engineers per year. This amounts to about a 6% annual increase in the number of engineers. When we compare this with our Institute's growth rate of 24%, it appears that Industrial Engineers are increasing at a rate four times as fast as other branches of engineering. This is felt to be conservative because there are many industrial engineers who have not joined A. I. I. E. and therefore are not included in the 24% growth curve. This increase, of course, is triggered by the increased demand for services of this nature. This explosive growth has a side effect for the more experienced engineers by creating more opportunities in engineering management which will provide the training, supervision and control of the overall engineering effort.

I predict a continuation of the trend toward newer techniques and the use of mathematical tools such as electronic computers and data processing equipment to solve the intricate problems of work design. New techniques for controlling cost of not only the manufacturing process, but the product design effort as well, will be brought into play.

Perhaps the major development ahead of us is unity in the engineering profession. The profession has no true counterpart to the American Medical Association and the American Bar Association. The National Society of Professional Engineers, which makes registration a prerequisite of membership, has about 50,000 members, or about 30% of the total number of registered engineers. At the present time about twenty engineering societies are federated in Engineers Joint Council with a combined membership of approximately 300,000. The Engineers Council for Professional Development is composed of eight societies, five of which are also included under EJC. Total membership of ECPD is approximately 200,000.

Past-president L. R. Howson of the American Society of Civil Engineers very ably summarized the current status of efforts towards unity in the engineering profession at a meeting in St. Louis last year. He pointed out that while individual engineers want unity in the profession, few have defined the term in their own minds or analyzed the means by which it might be effected. The Engineers Joint Council offers the most promising hope of unity since "splintering" started nearly a century ago. The merger of ECPD and EJC into a single corporate structure is now in process, bringing unity closer to realization. Mr. Howson feels, and most of us agree, that the eventual unity organization should embrace all engineering societies, acting for them on matters of common interest but permitting each society to pursue by itself or in groups the specific activities in which it has interest and proficiency. I believe that progress is being made and will continue until unity is realized, perhaps in this decade.

I have tried to look back briefly to our accomplishments and then to look ahead to the challenges that await us in the Sixties. In looking back, I would be remiss if I did not acknowledge the excellent work of the administrations that preceded mine. I want to take this opportunity to thank all the officers, national directors, chairmen and chapter presidents for their wonderful cooperation and enthusiastic response toward the tasks we faced. That we have succeeded is a tribute to their loyalty and ability. I want to commend to you the excellent opportunity you have in the papers and panels that have been provided for your enjoyment and enlightenment at this conference. I urge you to take part to the limit of your ability. You will leave here a better engineer and you will be able to better reflect credit on our profession.

I have enjoyed my year of service as president of our Institute. I must admit that there were times that I doubted the wisdom of my decision to accept the nomination. However, in retrospect I must admit that I thoroughly enjoyed the opportunity I had of meeting so many of our members throughout this great nation of ours. Even the problems encountered as a routine part of a vast operation like ours became a challenge. I assure you that your Institute will be in good hands next year under the able and devoted leadership of Dr. Alex W. Rathe. Thank you for your patience and attention.

PRACTICAL INDUSTRIAL ENGINEERING RESEARCH APPLICATIONS

by **HENRY M. OWADES**
Manager

OFFICE & LABORATORY SERVICES
MERCK, SHARP & DOHN RESEARCH LABORATORIES

Mr. Owades is graduate of New York University with a Masters degree in Industrial Engineering. He is a charter member of the New York chapter of A I I E and has served as President of that organization. He is currently active both in Chapter and National affairs of the A I I E.

From 1946 to 1949 he was Supervisor of Production and Planning for International Division of T. W. A. 1951-1956 he was a Project Engineer Research and Development for American Rosch Arma Corporation, Garden City, Long Island, New York. 1956-1957 Senior Industrial Engineer, Merck & Co., Inc. and has been in his present position as Manager of Research Services since 1957.

RESEARCH LABORATORIES — A NEW HORIZON FOR INDUSTRIAL ENGINEERS

by HENRY M. OWADES

Manager of Research Services, Merck, Sharp & Dohme Research Laboratories

WITH the American Institute of Industrial Engineers embarking on one of its greatest years, it is fitting that the theme of this conference be "New Horizons For Industrial Engineers". The Committee for the 11th Annual Conference is to be commended for selecting this timely theme. It is my pleasure this morning to present one of these new horizons to you. I would like to talk about the opportunities—no, the absolute need for more intensive applications of the principles and techniques of industrial engineering to research laboratories.

To do this, we will discuss:

a. the enormous potential that exists in research laboratories.
b. some of the applications of industrial engineering in the Merck Sharp & Dohme Research Laboratories Division.
c. some of the problems that are as yet left untouched.

Before we can discuss this potential, let us define the terms. For our purposes, a research laboratory is an organizational entity of considerable size whose primary function it is to discover, design, and-or develop new products or ideas. This paper is not particularly applicable to a research function which is a fractional part of a man or a group's activities. While the techniques which will be discussed here have been applied primarily in an industrial laboratory, they are applicable to university research laboratories, independent research groups, or governmental research agencies.

Industrial research in the United States in 1958 was a seven billion dollor business, employing over a half a million people in approximately 5,000 laboratories. Research expenditures for the larger companies in the United States range from approximately 1% to 8% of sales. To present another facet of this data, let us look at a hypothetical company with sales of $100,000,000. Assuming an average expenditure for research of 3%, they are spending $3,000,000 per year. Using Fortune magazine's average net profit on sales of 5%, they earn $5,000,000 after taxes, or approximately $10,000,000 before taxes and $13,000,000 as their pre-tax, pre-research profit. Hence this company needs an increase in sales of $800,000 for every $100,000 increase in its research allocation. Therefore, research is not only a big and costly expenditure, its leverage on the total financial picture of the company is great.

From the point of view of manpower, approximately half of the 500,000 people employed in industrial research are scientists and engineers, the other half are technicians, service personnel, and administrative staffs. Either of these groups contains a population large enough to warrant an Industrial Engineering analysis.

There is one additional parameter of a research activity which is often of more importance than the financial potential—and that is the time factor. Most research is conducted against a time deadline. In industrial research there is an intense, competitive race against time to market a new product before your competitor does. In some industries, the difference of several days can make the difference of many millions of dollars of sales or the long range capture of a major portion of the market. In military research it is unnecessary for me to repeat what has already been said many times over concerning the importance of time. The potentialities for industrial engineers to save time for the research scientist and engineers are perhaps greater than the potential for financial savings. This will be illustrated in our next point.

And that point is some examples of Industrial Engineering as applied in my own company—the Merck Sharp & Dohme Research Laboratories Division of Merck & Co., Inc. A standard question which is almost always presented in discussions such as this, is, "How did you get started?" or "How did you sell your management on using industrial engineers in the research laboratories?" This is indeed a fair question, and I think it is important for me to answer it at this time. In order to answer it I must give you a brief picture of my company, with particular emphasis upon the industrial engineering functions within the company.

Merck & Company is the parent organization of four operating divisions. They are:

1. the international Division, which handles the sale of our products outside the United States.
2. the Merck Chemical Division, which manufactures and sells bulk chemicals.
3. the Merck Sharp & Dohme Division, which formulates and packages pharmaceuticals and biologicals.
4. the fourth is the Research Laboratories Division, which is the central Research arm of the company.

The Research Division is physically located at two locations and is a "tenant" at each location. In Rahway, New Jersey it is a tenant of the Chemical Division; and at West Point, Pennsylvania a tenant of the Merck Sharp and Dohme Division. We, therefore, "buy" certain services from our "landlord"; amongst these is engineering services. Within the engineering department of the Chemical Division there is an industrial engineering group.

The philosophy of this group is to hire, train, and then transfer their engineers to operating positions in the company. If you reflect for a minute, you will see the wisdom of this philosophy. A department head who is trained and oriented as an Industrial Engineer can recognize or forestall problems *more readily* than a non-Industrial Engineer. Much of the time ordinarily spent in "selling" a manager on the need for an Industrial Engineering study is usually saved. It is more common under these conditions for the department manager to request the study on his own. Knowing the techniques, he has confidence in the results. And being responsible for the operation of the department, he will implement the recommendations.

This is how we "sold" our management on using Industrial Engineering in the laboratories. They weren't sold the techniques, they merely hired an Industrial Engineer to run a department. That engineer is your speaker. I would like to add at this point, that the senior Industrial Engineer whose staff performed the studies and who shares significantly in these accomplishments is John P. Fitzgerald. Mr. Fitzgerald was recently appointed Assistant Traffic Manager of the Chemical Division, and I fully expect that we will soon be hearing about another new horizon.

My department is responsible for a wide variety of non-technical services rendered to the research scientists. The group selected for the study was the laboratory servicemen. This is a group of 25 hourly employees who clean the laboratories, wash the glassware, deliver supplies to the scientists, and perform other related and miscellaneous tasks. This was the first group selected for a set of definite reasons.

(1) Of the sections in my department, this group has the closest contact with the scientific staff. If changes could be made in any group, this one would have the most immediate payback in terms of improved service.
(2) The scientific staff had expressed their general dissatisfaction with the level of service this group was offering.
(3) Improvements in this group would produce the most dramatic impact on the scientific staff and improve considerably the opportunities for additional industrial engineering studies.

We followed the standard textbook approach in making the study. We decided upon a work sampling study to determine the facts. The Union officials were called in before the study was announced. They were told what the study was all about; the purpose of the study; the techniques to be employed; and they were given a brief explanation of the techniques of work sampling. After this, the servicemen themselves were called in and given essentially the same run-down. They were introduced to the staff industrial engineer who would be making the study and were given an ample opportunity to ask questions and to grind any axes publicly, which they would otherwise do privately. The facts collected from this study pointed the direction for our future work. The facts indicated essentially the following:

(1) 30% of the servicemen's time was spent in handling glassware.
(2) 25% of the servicemen's time was spent in running errands of all sorts for the scientists.
(3) 20% was spent in rendering miscellaneous laboratory services (cleaning, setting up, etc.).

The balance of their time was spent in allowable personal time, non-allowable personal time, and unaccounted for time.

The information obtained from the study enabled us to divide the project into three separate and distinct phases. The first phase covered the delivery of supplies to the scientists. The Research Laboratories are spread over a wide area; specifically, they occupy seven buildings and a total of fourteen levels within these buildings. The stockroom is located in one of the buildings and services the entire research area. Concurrent with the work sampling study made of the laboratory servicemen, a second study was made of the stockroom. This study showed us that approximately 80 scientists per day were coming to the stockroom for their own supplies. At an average of 15 minutes per trip, this is the equivalent of two full-time scientists acting as errand boys. This pointed to the need for re-organizing the delivery of supplies, and this is what we did:

(1) We re-assigned three lab servicemen and made them full time delivery men.
(2) We had specially designed hand-trucks and tote bins made to carry the supplies.
(3) We installed an answering device on the telephone in the stockroom.
(4) We re-designed the stockroom to fit the new method of operation.
(5) Before any of this was done, we held a meeting with the scientific staff to discuss their needs and how this change would meet them.

The delivery system operates this way. The laboratory phones their order into the stockroom. The information is written down (it is first put on the wire-recorder of the answering service if the clerk is occupied elsewhere). The requested material is placed in tote boxes and transported to the laboratory by one of the delivery men.

This has been in effect almost two years. We have been handling 70 calls a day, more than 75% of which are completed within 1½ hours. A recent survey indicated we now have less than ten scientists a day visiting the stockroom.

In addition to merely saving manpower, we have enabled the laboratory personnel to do some advance planning on their material requirements. We have received many calls asking that certain supplies be available in a particular laboratory several days hence.

The objectives we set for ourselves at the outset of this first phase were met completely. The response from the scientific staff was heartening and it established the needed "acceptance" for the rest of our program.

Here is a partial list of the additional improvements made:

(1) By re-designing the stockroom, we not only provided the division with an efficient stockroom, we increased the utilization of the stockroom personnel, and were able to convert 600 sq. ft. into a laboratory. At going prices this represented a savings of $30,000 and provided space of a laboratory that was urgently needed for a new research program.

(2) Automatic glassware washing equipment was installed that improved the quality and the speed of this service. Incidentally, here too we made additional space available which has since been converted into a laboratory.

(3) We have worked with the scientists in the design of several new laboratories. I will have more to say on this later on.

Having discussed briefly some of the very simple problems which were improved by using some traditional techniques of industrial engineering, I would like to touch upon some additional ones which need our help.

(1) The entire area of the physical facilities which the scientist works with has been largely neglected. For example, his laboratory work place is not designed properly. It does not provide for flexibility or for adequate use of the cubic space of the room. The utilities which are piped into his bench are not carefully considered as to type, control, or need. They have been traditionally considered only from the point of view of initial economy of construction.

(2) The services needed by the researcher needs additional analysis. The delineation of what is a service and what is research should be clarified within each company. Designing these service functions so that they are and remain in step with the tempo and time of the research program is another major problem for us to consider.

(3) Finally, and only for the sake of brevity and not because the list is exhausted, the entire area of research decision making needs assistance. This is being given great scrutiny by many people. My own company has such a program under way. But this problem is so complex, and and the stakes so high, that it can profit from additional analysis.

Recent studies made have indicated that the cost of servicing a single Ph. D. senior scientist runs in the neighborhood of $100,000 per year. Lest you misunderstand this, this is not exclusively his salary. This includes the salary of the technicians, the junior scientist, the supplies, the physical facilities, and the administrative staffs necessary to service a senior scientist. The hypothetical company we mentioned earlier must increase its sales by $800,000 to break-even when they add a senior investigator. I make this point again not to frighten you—I merely want to point out that when playing in a poker game where the chips come this high, learning some of the rules becomes almost mandatory if one is to survive.

In concluding this paper, I would like to make several points to those of you who may have the opportunity to work in a research laboratory.

(1) The traditional tools of our profession are more than ample for many of the jobs that need doing in a research lab. In the work we have done we called upon the techniques of work sampling, work simplification, and plant layout for most of our activities.

(2) The by-word of an Industrial Engineering program of this type should be "Service Improvement" rather than "Cost Reduction". It is often difficult to measure quantitatively the dollar value of improved service or of research time saved. Be careful lest you fall into the trap of not implementing a project because you can only measure the cost but not the savings.

(3) The research scientist needs the help of the engineer first in establishing specifications and then in converting these specifications into practical reality. Most people outside the research laboratory are often prone to discount his requirements as being "impractical, long haired," etc. He needs your help to tell these people just how realistic these requirements are.

You can make a significant contribution to your company and to our economy if you would seek out the opportunity to exploit this new horizon.

SOME PROPOSALS FOR A UNIFIED PROGRAM OF MANAGEMENT CONTROLS

by JOSEPH D. CARRABINO

GRADUATE SCHOOL OF BUSINESS ADMINISTRATION
UNIVERSITY OF CALIFORNIA

Dr. Carrabino did his undergraduate in Engineering and business Worcester Polytechnic Institute, his Masters work at Northwestern University and received his Ph.D. degree in Engineering at the University of California. In 1958 he was given a Fulbright Lectureship Grant to Italy. In Italy he served as a Consultant at Management Centers and Educational Centers.

He is currently a member of American Arbitration Association and has served as a Consultant to numerous companies and labor unions. In addition to membership in seven Professional Societies, Dr. Carrabino also holds membership in four Honorary Societies including Tau Beta Pi.

SOME PROPOSALS FOR A UNIFIED PROGRAM OF MANAGEMENT CONTROLS

by DR. JOSEPH D. CARRABINO

Chairman, Production Management Division and Associate Professor of Production Management, Graduate School of Business Administration, University of California, Los Angeles

HISTORICAL BACKGROUND OF SCIENTIFIC

BEFORE embarking on a discussion of management controls it may be profitable to take a kaleidoscopic view of what I like to call the three industrial revolutions which have set the stage for the current environment in which the industrial engineering profession finds itself.

FIRST INDUSTRIAL REVOLUTION (Mechanization)

Here we began to substitute machinery for the human and animal "brawn" contribution to a production system. Approximate dates quoted by historians for this First Industrial Revolution are: England, about 1770 and the United States about 1790. The principle of specialization of labor was widely adopted as we replaced more and more hand work by machinery. The invention of machine tools (the "master tools" of industry) made possible interchangeable manufacture. The developments were all essential concomitants of mass production techniques.

SECOND INDUSTRIAL REVOLUTION

This Second Revolution got under way in the United States about 1900 under the leadership of Frederick W. Taylor who is considered the "father" of the scientific management movement. His contributions reflected the philosophy of substituting a fact-finding approach for rule-of-thumb operation. Essentially, we can say that he demonstrated the efficacy of applying scientific methodology to the analysis of "man and machine" systems whereas prior to this time such methodology was applied only to physical systems. Since the end of World War II we have seen the development of many new and more sophisticated methodologies and techniques such as operations research, linear programming, game theory, job enlargement, and electronic data processing using high-speed digital computers.

The scientific management movement has given impetus to the:

1. Development of emphasis on study of human relations problems.
2. Growth of management development programs of all types at all managerial levels.
3. Growth of labor movement and its many programs for coping with problems generated by the three industrial revolutions.
4. Growth of a professional "managerial class."

THIRD INDUSTRIAL REVOLUTION (Automation)

During and since the end of World War II we have begun to substitute for the "brains and sensory apparatus" of human beings in production systems. Automation type equipment is characterized by servomechanisms which include sensing devices which tell when a process is out of control and signal control devices to make proper adjustments. The "Detroit Type Automation" is different from automation which is based on the feedback principle made possible by servomechanisms. It is the mechanical linking together of conventionally separate manufacturing operations so that automatic transfer of parts is achieved.

The common denominator between all three industrial revolutions is that the human contributions to the production system is eliminated, reduced, or modified. The recent developments of numerically-controlled machine tools are especially worthy of note to the industrial engineer since they portend radical changes in industry which will diminish further the man component in production systems. The industrial engineers tool kit for rationalizing and measuring manual effort will become less and less useful as this effort is replaced by mechanization and automation type equipment. Increasingly useful will become the knowledge of computer technology and the techniques for conducting equipment replacement type studies.

MANAGERIAL FUNCTIONS OF PLANNING AND CONTROL

The functions of all managers at all levels in all enterprises may be defined as follows (1):

1. *Planning* — involves the selection, from among alternatives, of enterprise objectives, policies, procedures, and programs.
2. *Organizing* — involves the determination and enumeration of the activities required to achieve enterprise purposes, the grouping of these activities, the assignment of them to a subordinate manager and the delegation of authority to carry them out, and provisions to permit the desired type of coordination among managers and subordinates.
3. *Staffing* — comprises those activities which are essential in manning, and in keeping manned, the executive positions in an enterprise.
4. *Direction* — embraces those activities which are related to guiding and supervising subordinates.
5. *Control* — includes those activities which are designed to compel events to conform to plans. This formulation of the concept embraces the idea that the planning activities must precede control and that plans alone are not self-achieving. The control process involves three steps:
   1—The determination of standards—"what should be accomplished."
   2—The appraisal of performance—"what has been accomplished."
   3—Comparison of the actual performance with standards and correction of deviations.

A statistical quality control chart is an example of a control device whose use embodies the three steps of the control process.

The managerial functions of planning and control can be performed more effectively by supplementing the limited traditional controller's activities with the methodologies and techniques of industrial engineering and operations research. At this point I would like to review briefly the historical and current positions of each of these three fields in business and industry and then proceed to a discussion of ways in which their contributions may be integrated; thereby achieving unified programs of management controls.

FUNCTIONS OF THE CONTROLLER

The functions of the controller, as determined from a study of a number of company organization manuals, job descriptions, and interviews, are summarized (American Management Association Research Report No. 20) by Dale (2) as follows:

1. Providing basic information for managerial control through formulation of accounting and costing policies, standards and procedures, preparation of financial statements, and maintenance of books of account; direction of internal auditing and cost controls.
2. Budgeting and control of operations and results.
3. Specific control activities.
   a. General accounts, primary and subsidiary accounts; devising checks on the company's finances and safeguarding its assets; checking invoices, accounts receivable and payable; controlling cash payments and receipts, payroll accounts, fringe benefits, plant and equipment records; cost accounting activities of the various management functions.
   b. Preparation and interpretation of regular financial reports and statements.
   c. Inventory control.
   d. Statistics.
   e. Taxes.
4. Internal audits.
5. Interpretation of control data.

Historically, the controller has been the chief accounting officer of a company. He has concerned himself primarily with statistical and financial data and the emphasis has been on the reporting of historical information. When looked at from the modern concept of control, the name controller appears to be a misnomer since in fact only part of the control process has been performed. There is very little in the educational background of accountants which would prepare them to perform measurement activities and in my opinion measurement is the essence of the control process. If this is so, then it is obvious that an engineering education is excellent preparation for the performance of the control process.

From the viewpoint of the managerial function of planning it is difficult to see how the controller's function as currently practiced could make more than trivial contributions. The simple methodologies and equally simple techniques comprising the tool kit of the controller could hardly cope with the complexities presented by analyses requisite to the "selection from among alternatives of objectives, policies, procedure and programs."

FUNCTIONS OF INDUSTRIAL ENGINEERING

In 1955 the American Institute of Industrial Engineers adopted the following definition of industrial engineering:

"Industrial Engineering is concerned with the design, improvement and installation of integrated systems of men, materials and equipment; drawing upon specialized knowledge and skill in the mathematical, physical, and social sciences together with the principles and methods of engineering analysis and design, to specify, predict and evaluate the results to be obtained from such systems."

This is a masterfully worded definition so generic in nature that it appears to subsume all fields of engineering. This elevation of industrial engineering in the engineering hierarchy from a peripheral status to a sovereign one can hardly be accomplished via the semantic route. Starting with the works of Frederick W. Taylor the industrial engineering profession has been intimately associated with manufacturing activities. The techniques of methods improvment, work measurement, wage incentives, and plant layout have been the most prominent ones. Unfortunately, this is still the majority situation in American industry and this is the connotation which the word industrial engineering still has not only among laymen but also among businessmen and academicians.

Historically and currently cost reduction and cost control programs in industry have been focused on the manufacturing function. Industrial engineers with some help from accountants have been called on to provide the know-how to perform the three steps of the control process in manufacturing. This partial and sub-optimization approach to cost control is still the vogue today as seen in recent announcements of cost reduction training programs conducted by such elite organizations as the American Management Association.

Industrial engineering has been called on to help in performing the managerial function of planning to very limited extents. Perhaps it may be argued by way of excuse that this is the most neglected of all managerial functions and that the fault lies with management. On the other hand it may be argued that management usually adopts methods when they are available and their efficacy has been demonstrated.

On examination of the situation with regard to the planning and control of operations in the other functional areas of management such as research, engineering, and marketing reveals a distressing picture. Management has only in rare instances called on industrial engineers to exercise their skills in these areas. Tremendous opportunities for cost reduction and control exist in these areas, particularly in government financed industries such as aircraft and missile where, for example, underutilization of engineers is mistaken for a shortage of engineers. The problem of measurement is indeed difficult in these non-manufacturing areas but many industrial engineering techniques such as work sampling could be adapted to replace the present informal controls with measurement-based controls.

Industrial engineering applications in non-manufacturing fields have been numerous in post-war years but we must not overlook the fact that the techniques used have been fairly elementary.

Futher comments on industrial engineering will be reserved for a later section where I strongly urge that the American Institute of Industrial Engineers give immediate consideration to changing its name to one which is in greater consonance with the aforementioned official definition of industrial engineering and with the emerging broad field of applied management science.

FUNCTIONS OF OPERATIONS

In April 1951, the Committee on Operations Research of the National Research Council published a brochure entitled "Operations Research with Special Reference to Non-Military Applications" with the object of acquainting American management with what was then a new management tool. At that time, operations research, as an organized activity under that name, was already more than ten years old and had amassed a distinguished record of accomplishment for the military, both British and American, in World War II—and was adding to its record of military accomplishment in Korea. This and subsequent events have had a "sputnik like" effect on the industrial engineering profession.

Ellis Johnson claims (3) that the most important characteristics of operations research are:

1. Research on the operations of the whole organization.
2. Optimization of operations in a manner that brings about greater assurance of both short and long range health for the organization.
3. Application of the newest scientific methods and techniques.
4. Synthesis and extension of the methods and techniques of the older management sciences.
5. Development and use of analytical models in the manner common to the basic sciences.
6. Design and use of experimental operations that that give an insight into the behavior of actual operations.
7. Use of integrated and creative multi-disciplinary team research to solve complex operational problems.

It seems that the aforementioned AIIE definition of industrial engineering subsumes also these characteris-tics of operations research. An examination of the literature of operations research and industrial engineering reveals many similarities. The Institute of Management Sciences is another organized group whose objectives "to identify, extend, and unify scientific knowledge that contributes to the understanding and practice of management" appear to parallel those of the AIIE and the Operations Research Society of America.

The dividing line which I see forming gradually between these three groups is that ORSA and TIMS are concentrating on more fundamental mathematically oriented management sciences, whereas AIIE efforts (at the best level) are concentrated on applied management sciences or management engineering. This dividing line is analagous to that between physics and chemistry with engineering. This appears to be a proper division of labor between these egroups.

UNIFIED PROGRAM OF MANAGEMENT

It should be obvious by now that a unification of the meeasurement-oriented elements of the controllers function, industrial engineering, and operations research is desirable since all three groups purport to have similar philosphies and objectives. I believe that we can accelerate this unification by combining the measurement-oriented elements of these three fields into a new field which I shall for the moment call management engineering. In other words:

Controllership Function + Industrial Engineering + Operations Research = Management Engineering.

I propose setting up a separate management engineering group for each functional area of management, i.e., research, engineering manufacturing, and marketing. I propose a separate management engineering group at the general management level. This central unit would be responsible for coordinating and integrating the efforts of each of the functional area units.

The management systems in each of the functional areas and at the general management levels have characteristics sufficiently different as to warrant the use of specialized management engineering groups. The need at the general management level is particularly critical with the rapid development of new technologies which are making possible the rapid processing of large amounts of information and the simulation of management decision making processes by means of high-speed computers. More and more articles (4) and (5) in the recent literature discuss this critical need.

PROPOSED CHANGE IN NAME IN AMERICAN INSTITUTE OF INDUSTRIAL ENGINEERS

I strongly urge that the AIIE give immediate consideration to changing its name to one which is in greater consonance with the emerging broad field of applied management sciences. Since the word management sciences is becoming widely associated with work related to the development of fundamental analytical tools and methodologies it would seem logical to use the name management engineering to describe the work related to the application of these fundamental tools and methodologies to management systems. The present image of industrial engineering held by people outside the profession (also within) is not consonant with the image created by the official definition by the AIIE. The very best current practice and certainly the majority practice of the future merit a break with many past practices which could hardly be classified professional activities. In fact, if present trends are allowed to continue people called industrial engineers will be thought of and used as technician — like assistants to the "professional" operations researchers and management scientists.

The present (mostly simple) and future (we hope sophisticated) applications of industrial engineering to non-manufacturing areas warrant a break with the restrictive word "industrial" with all its manufacturing connotations and the ever present ugly image of the time study man.

Many other arguments could be presented for a change in name for the AIIE but I shall reserve such arguments for treatment in a separate article.

TRENDS IN UNIVERSITY SCHOOLS OF ENGINEERING AND BUSINESS ADMINISTRATION

Traditionally University Schools of Business Administration have been "dumping off" points for Engineering Schools, veritable descriptive havens from the quantification rigors of engineering. However, the picture has been changing rapidly, at least in the best of the business administration schools. References (6) and (7) are recent studies which have put a strong spotlight on business administration programs and which have already had many salutary effects. Business administration schools are rapidly taking on the characteristics of engineering schools with the increasing introduction of quantitative methods in the curriculum. They are in the lead with respect to the consideration of behavorial sciences. "Maverick-like" faculties include mathematicians, psychologists, sociologists, engineers, etc. The domination of the economists and accountants is coming to an end.

I predict that in the future more and more engineering schools will drop out of the management business. The line which I see drawing sharper each day is one where engineering schools will concentrate and specialize on physical systems and business administration schools will take over the study of man and machine systems. The environment in industrial engineering departments of engineering schools appears to be too limited to considerations of manufacturing operating systems, processes, materials, tooling, etc. A broad consideration of the managerial decision making process must be made in a complete environment which includes all the functional areas of managements, particularly marketing and finance. It is difficult to see how such factors as strong prejudices and the marginal status of industrial engineering in engineering schools can be corrected in the face of competition for resources from the important and glamorous nuclear and space programs.

In my opinion the future source of broadly educated manpower for the management engineering profession will come from business administration schools. These schools will play an increasingly important role in management education while that of engineering schools will continue to be a minor one. These trends provide another powerful reason why the AIIE should re-evaluate its position and consider seriously a change in name.

REFERENCES

1. KOONTZ, Harold and O'DONNELL, Cyril, *Principles of Management,* McGraw-Hill, New York, 1955, pp. 34-36.
2. DICKEY, Robert I., Editor, *Accountants' Cost Handbook,* Ronald Press, New York, Second Edition, 1960, section 4, p. 21.
3. McCLOSKEY, Joseph F. and TREFFTHEN, Florence N., Editors, *Operations Research For Management,* The Johns Hopkins Press, Baltimore, p. XIV.
4. FORRESTER, Jay W., Industrial Dynamics, *A Major Breakthrough For Decision Makers,* Harvard Business Review, July-August 1958, pp. 37-66.
5. LEAVITT, Harold J. and WHISLER, Thomas L., *Management in the* 1980's, Harvard Business Review, November-December 1958, pp. 41-48.
6. PIERSON, Frank C. and others, *The Education Of American Businessmen -A Study of University-College Programs in Business Administration,* McGraw-Hill, 1959.
7. GORDON, Robert Aaron and HOWELL, James Edwin, *Higher Education For Business,* Columbia University Press, New York, 1959.

section 4

TOTAL SYSTEM CONCEPT — BELL HELICOPTER

by THOMAS C. FISHER
Manager

DATA PROCESSING
BELL HELICOPTER CORP.

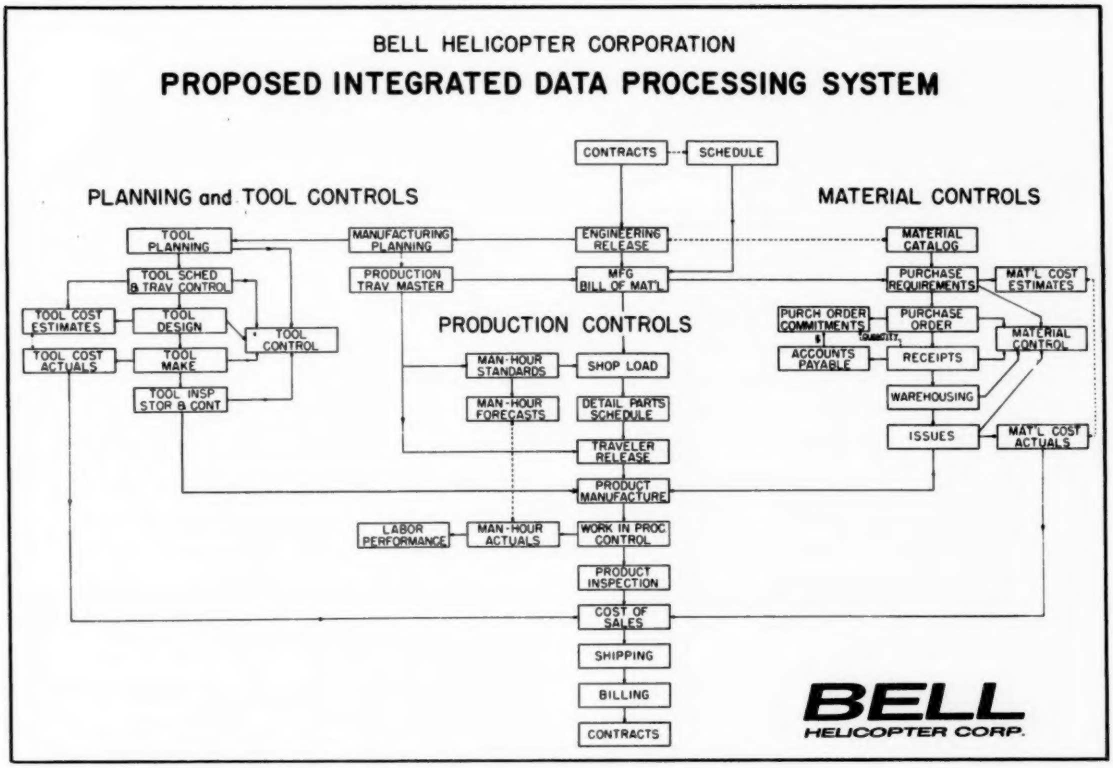
Having graduated from United States Marine Academy, Mr. Fisher served as a Destroyer Engineering Officer during World War II. After the war, he continued his education by doing post graduate work at the University of California.

He has a wide business and engineering background, having held such positions as Industrial Engineer with Bethlehem Steel, Assistant Production Manager with the Axelson Manufacturing Corporation, Washington Military Representative of the Northrop Aircraft Corporation and as a Regional Stall member of the I. B. M. Corporation.

TOTAL SYSTEM CONCEPT—BELL HELICOPTER CORPORATION

by T. C. Fisher

Manager of Data Processing



BELL HELICOPTER CORPORATION
PROPOSED INTEGRATED DATA PROCESSING SYSTEM
CONTRACTS
SCHEDULE
PLANNING and TOOL CONTROLS
MATERIAL CONTROLS
TOOL PLANNING
MANUFACTURING PLANNING
ENGINEERING RELEASE
MATERIAL CATALOG
TOOL SCHED & TRAV CONTROL
PRODUCTION TRAV MASTER
MFG BILL OF MAT'L
PURCHASE REQUIREMENTS
MAT'L COST ESTIMATES
TOOL COST ESTIMATES
TOOL DESIGN
TOOL CONTROL
PRODUCTION CONTROLS
PURCH ORDER COMMITMENTS
PURCHASE ORDER
MATERIAL CONTROL
TOOL COST ACTUALS
TOOL MAKE
MAN-HOUR STANDARDS
SHOP LOAD
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QUANTITY
ACCOUNTS PAYABLE
RECEIPTS
TOOL INSP STOR & CONT
MAN-HOUR FORECASTS
DETAIL PARTS SCHEDULE
WAREHOUSING
TRAVELER RELEASE
ISSUES
MAT'L COST ACTUALS
PRODUCT MANUFACTURE
LABOR PERFORMANCE
MAN-HOUR ACTUALS
WORK IN PROC CONTROL
PRODUCT INSPECTION
COST OF SALES
SHIPPING
BILLING
CONTRACTS
BELL
HELICOPTER CORP.

I. MATERIAL CATALOG

A. Catalog Arrangement

The Material Code Catalog system is designed to provide a uniform method of identifying and cataloguing all of the materials required for production of helicopters as well as all other materials commonly in use at Bell Helicopter Corporation.

Catalogs containing materials which enter into the end product are maintained by Engineering in the following catalogs:

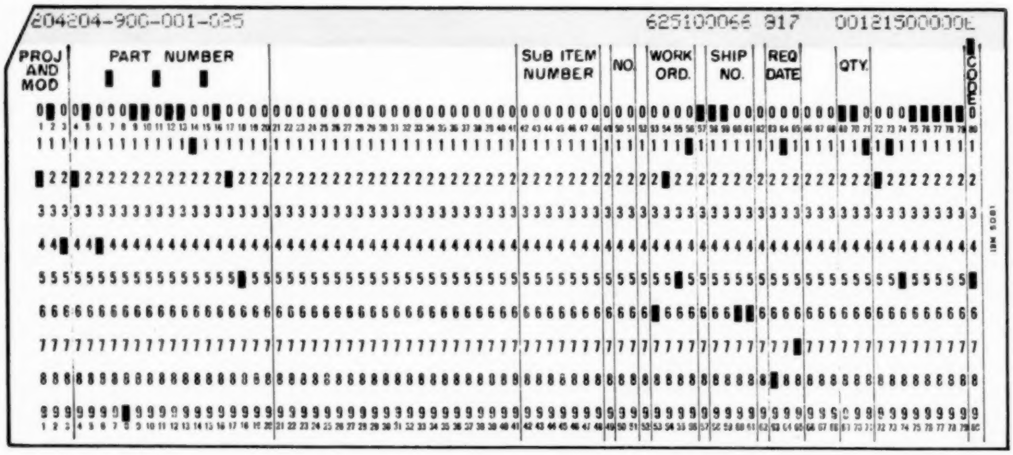
1. Metallic Catalog
2. Non-Metallic Catalog
3. Standards Catalog
4. Vendor Catalog

Catalogs containing materials for supporting operations are maintained by the department which normally monitors the requirements for this type of material, as follows:

5. Factory Supplies Catalog
6. Perishable Tools Catalog
7. Office Supplies and Forms Catalog
8. Maintenance and Repair Catalog

B. Catalog Usage

1. Define production requirements for materials in parts material file.
2. Specify production requirements on production work order and material requisition.
3. Procurement System - Used on purchase requisitions, purchase orders, receivers, and purchasing reports.
4. Warehousing - Code and description on warehouse bins for identification.
5. Accounting Systems - Accounts Payable to distribute charges and formulate commitment reports; also inventory records for perpetual and physical inventories.
6. Cost Estimates - Evaluation and relation of material cost files to ship build-up files.
7. Government Reports - Defense Material Systems reports and others as required.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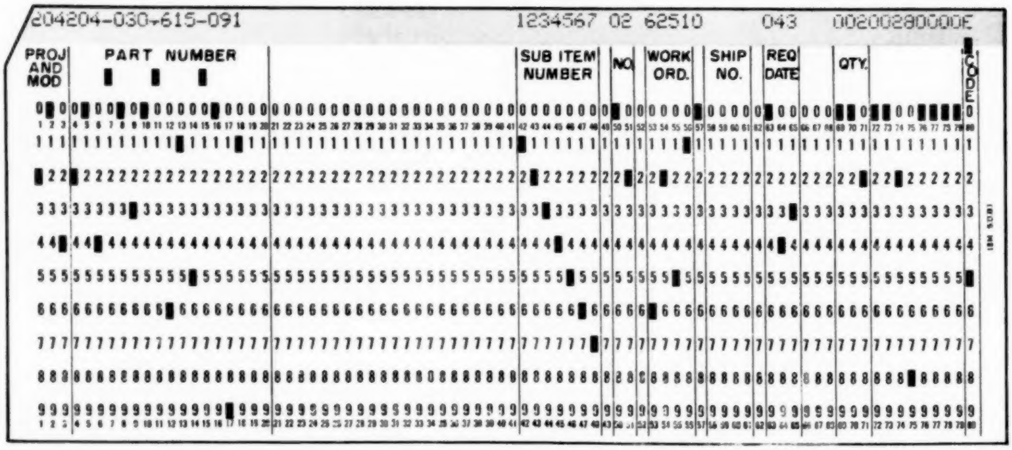
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SPARES CARD

II. CONTRACT REQUIREMENTS FILE

A. Contract File Content

The purpose of the Contract Requirement File is to provide in one complete file a record of the Company's backlog of business for both military and commercial.

These obligations will be shown as the end item which will be delivered to the customer. They will be identified to:

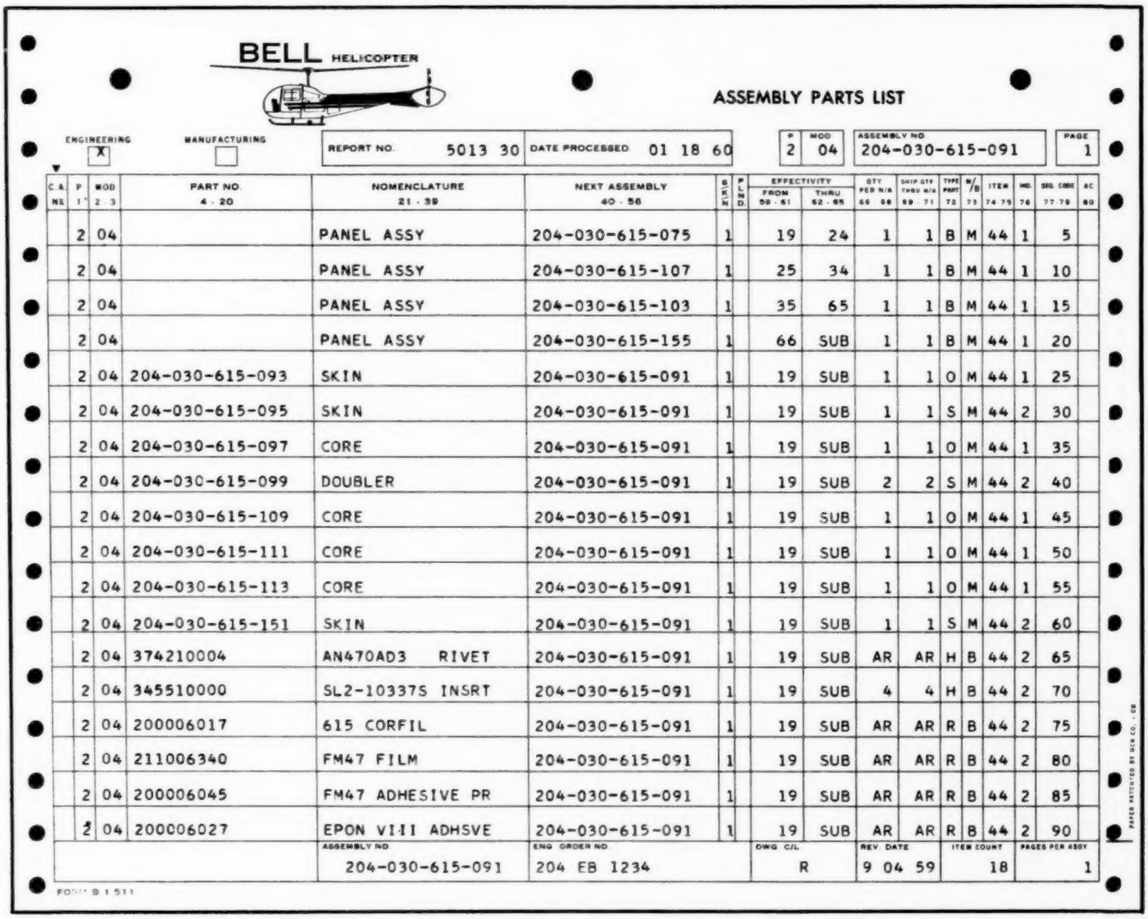
1. Project and Model
2. Part Number
3. Work Order
4. Ship Number (for complete ships only)

The basic information recorded is:

5. Requirement Date (company schedule)
6. Dollar Value

B. File Usage

1. Establish gross contract requirement
2. Forecast schedule of income in terms of dollar value
3. Create sales order manual
4. Summarize monthly sales order status report by project and model
5. Sales analysis reports
6. Serves as input to 650 gross requirements explosion



BELL HELICOPTER

ASSEMBLY PARTS LIST

ENGINEERING ☒ MANUFACTURING ☐

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P 2 MOD 04 ASSEMBLY NO 204-030-615-091 PAGE 1

C.A. NR.	P 1	MOD 2-3	PART NO. 4-20	NOMENCLATURE 21-39	NEXT ASSEMBLY 40-56	S/K/N	P L N D.	EFFECTIVITY FROM 58-61	EFFECTIVITY THRU 62-65	QTY PER N/A 66-68	SHIP QTY THRU N/A 69-71	TYPE PART 72	M/B 73	ITEM 74-75	NO. 76	SEQ. CODE 77-79	AC 80
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III. ENGINEERING RELEASE

A. Flow

The Engineering Assembly Parts List provides an up-to-date record reflecting the quantity and usage of parts, material and assemblies going directly into assemblies for each ship as defined by Engineering. The timely updating of the records is accomplished by flowing the original engineering document through the Data Release Group prior to engineering release. Capturing the basic engineering data at this point adds 24 hours to the engineering release cycle.

B. Organization

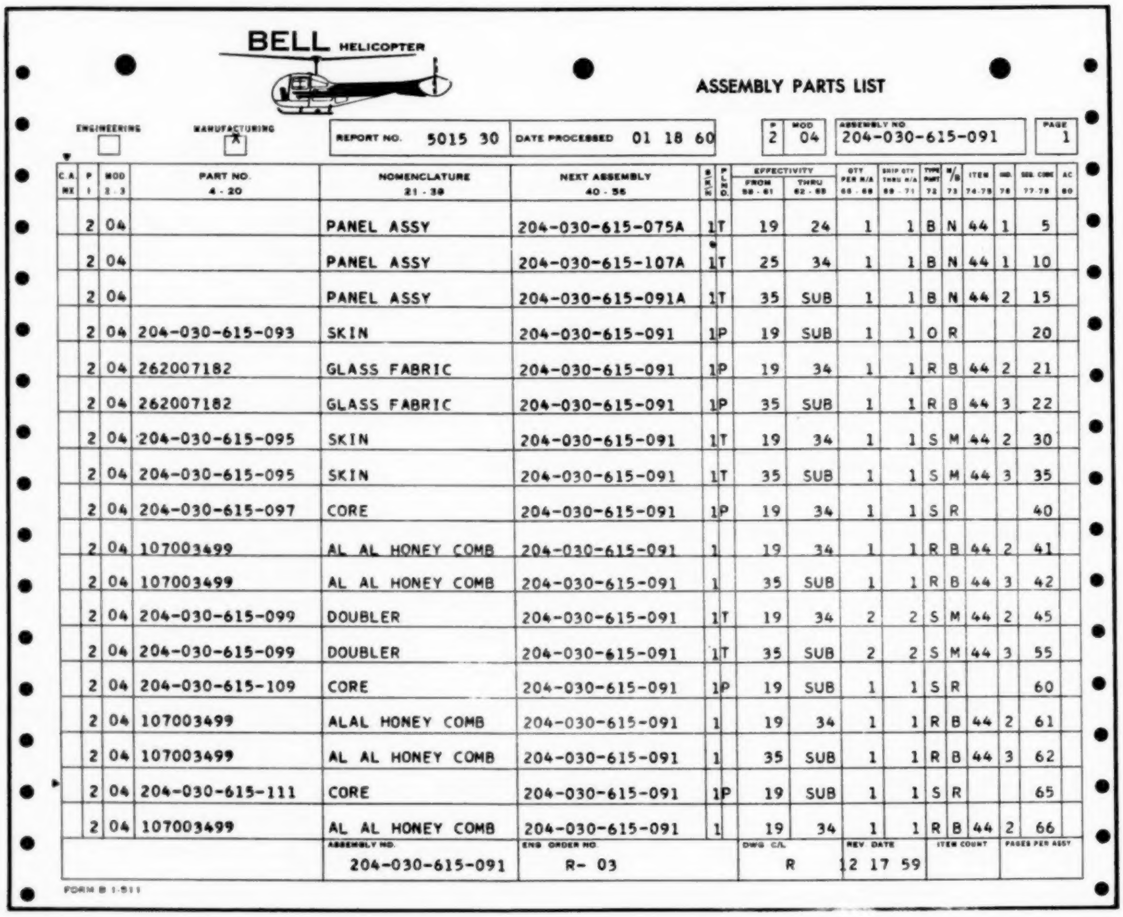
To obtain consideration by all the departments affected by a new release, the Data Release Group has been staffed with personnel from the Production Control, Production Planning and Spares Departments. This arrangement is unique in organization, as the people remain a part of their original department and represent that department's requirements, but function as a group under the direction of the administrative head of the Data Release Group. Subcontract decisions are provided daily by part-time representation from the head of the Manufacturing Board.

By providing data processing services to update files on a 24-hour basis, the latest engineering information is available for distribution concurrent with the release of the engineering documents. The information is distributed through the use of two-part forms for the master file maintained in Data Release and distribution copies printed from multilith masters.

C. Usage

These same basic files maintained in Data Processing serve as source data for the following types of reports:

1. Engineering Assembly Parts List
2. Engineering Bill of Material
3. Provisioning Parts for Military Spares
4. Illustrated Parts Catalog
5. Engineering Drawing Status Report



BELL HELICOPTER

ASSEMBLY PARTS LIST

ENGINEERING ☐ MANUFACTURING ☒

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P 2 MOD 04 ASSEMBLY NO 204-030-615-091 PAGE 1

C.A. MK	P 1	MOD 2-3	PART NO. 4-20	NOMENCLATURE 21-39	NEXT ASSEMBLY 40-56	S/K/N	PL NO.	EFFECTIVITY FROM 58-61	EFFECTIVITY THRU 62-65	QTY PER N/A 66-68	SHIP QTY THRU N/A 69-71	TYPE PART 72	M/B 73	ITEM 74-75	IND. 76	SEQ. CODE 77-79	AC 80
	2	04		PANEL ASSY	204-030-615-075A	1	T	19	24	1	1	B	N	44	1	5	
	2	04		PANEL ASSY	204-030-615-107A	1	T	25	34	1	1	B	N	44	1	10	
	2	04		PANEL ASSY	204-030-615-091A	1	T	35	SUB	1	1	B	N	44	2	15	
	2	04	204-030-615-093	SKIN	204-030-615-091	1	P	19	SUB	1	1	O	R			20	
	2	04	262007182	GLASS FABRIC	204-030-615-091	1	P	19	34	1	1	R	B	44	2	21	
	2	04	262007182	GLASS FABRIC	204-030-615-091	1	P	35	SUB	1	1	R	B	44	3	22	
	2	04	204-030-615-095	SKIN	204-030-615-091	1	T	19	34	1	1	S	M	44	2	30	
	2	04	204-030-615-095	SKIN	204-030-615-091	1	T	35	SUB	1	1	S	M	44	3	35	
	2	04	204-030-615-097	CORE	204-030-615-091	1	P	19	34	1	1	S	R			40	
	2	04	107003499	AL AL HONEY COMB	204-030-615-091	1		19	34	1	1	R	B	44	2	41	
	2	04	107003499	AL AL HONEY COMB	204-030-615-091	1		35	SUB	1	1	R	B	44	3	42	
	2	04	204-030-615-099	DOUBLER	204-030-615-091	1	T	19	34	2	2	S	M	44	2	45	
	2	04	204-030-615-099	DOUBLER	204-030-615-091	1	T	35	SUB	2	2	S	M	44	3	55	
	2	04	204-030-615-109	CORE	204-030-615-091	1	P	19	SUB	1	1	S	R			60	
	2	04	107003499	ALAL HONEY COMB	204-030-615-091	1		19	34	1	1	R	B	44	2	61	
	2	04	107003499	AL AL HONEY COMB	204-030-615-091	1		35	SUB	1	1	R	B	44	3	62	
	2	04	204-030-615-111	CORE	204-030-615-091	1	P	19	SUB	1	1	S	R			65	
	2	04	107003499	AL AL HONEY COMB	204-030-615-091	1		19	34	1	1	R	B	44	2	66	

ASSEMBLY NO.	ENG. ORDER NO.	DWG. C/L	REV. DATE	ITEM COUNT	PAGES PER ASSY
204-030-615-091	R- 03	R	12 17 59		

FORM B 1-511

IV. MANUFACTURING BILL OF MATERIAL

A. Flow

The Manufacturing Assembly Parts List is a record of the planned manufacturing build-up of the end product. It incorporates all changes between original engineering and manufacturing planning.

The Manufacturing Assembly Parts List is usually initiated simply by reproducing the Engineering Assembly Parts List into the Manufacturing Assembly Parts List file. The data is coded to indicate engineering only - not planning. This provides for incorporation of engineering release information into the Manufacturing Assembly Parts List file at the earliest possible date. As soon as Manufacturing Planning is completed on an item, it is reviewed by the Data Release Group. The Manufacturing Assembly Parts List file is updated to reflect the planned manufacturing sequence. Coding indicates the change from engineering to planning status.

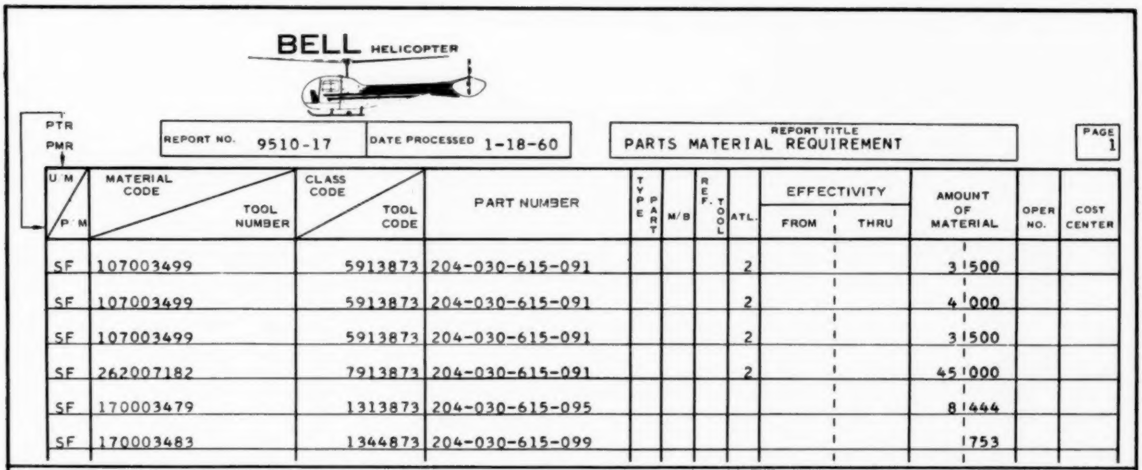
B. Decision Data

Decision data which is coded into the Manufacturing Assembly Parts List contributes much to subsequent programs. The following is a cross-section of this decision data:

1. Source code (S/K/N) - Indicates where used
   a. Normal Production Part - effective on ships and spares
   b. Spares Only Assembly - effective on spares only
2. Type of Part Code (Type Part) - Indicates length of manufacturing flow time required.
   a. Assembly - sheet metal, machined, bonded
   b. Detail - sheet metal, machined, electrical
3. Make or Buy (M/B) - Indicates subcontract
   a. Make detail - raw material requirement
   Buy, vendor furnish material
4. Item and Indenture - The schedule relationship between parts completion and completion of the end product.

C. Usage

A computer program uses this file as one of its principle sources of data in computing these requirements for parts and materials.



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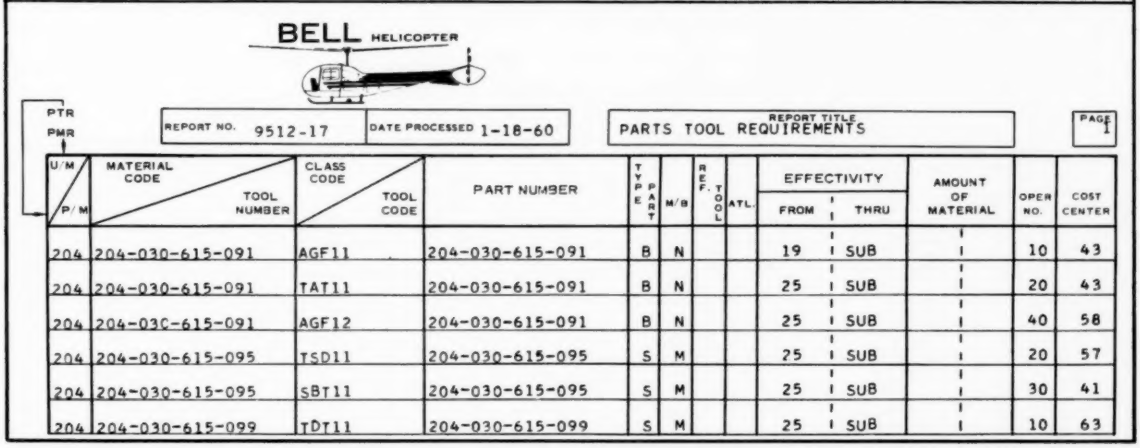
PTR
PMR

REPORT NO. 9510-17 DATE PROCESSED 1-18-60

REPORT TITLE PARTS MATERIAL REQUIREMENT

PAGE 1

U/M / P/M	MATERIAL CODE / TOOL NUMBER	CLASS CODE / TOOL CODE	PART NUMBER	TYPE PART	M/B	REF. TOOL	ATL.	EFFECTIVITY FROM	EFFECTIVITY THRU	AMOUNT OF MATERIAL	OPER NO.	COST CENTER
SF	107003499	5913873	204-030-615-091				2			3 500		
SF	107003499	5913873	204-030-615-091				2			4 000		
SF	107003499	5913873	204-030-615-091				2			3 500		
SF	262007182	7913873	204-030-615-091				2			45 000		
SF	170003479	1313873	204-030-615-095							8 444		
SF	170003483	1344873	204-030-615-099							753		



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PTR
PMR

REPORT NO. 9512-17 DATE PROCESSED 1-18-60

REPORT TITLE PARTS TOOL REQUIREMENTS

PAGE 1

U/M / P/M	MATERIAL CODE / TOOL NUMBER	CLASS CODE / TOOL CODE	PART NUMBER	TYPE PART	M/B	REF. TOOL	ATL.	EFFECTIVITY FROM	EFFECTIVITY THRU	AMOUNT OF MATERIAL	OPER NO.	COST CENTER
204	204-030-615-091	AGF11	204-030-615-091	B	N			19	SUB		10	43
204	204-030-615-091	TAT11	204-030-615-091	B	N			25	SUB		20	43
204	204-03C-615-091	AGF12	204-030-615-091	B	N			25	SUB		40	58
204	204-030-615-095	TSD11	204-030-615-095	S	M			25	SUB		20	57
204	204-030-615-095	SBT11	204-030-615-095	S	M			25	SUB		30	41
204	204-030-615-099	TDT11	204-030-615-099	S	M			25	SUB		10	63

V. MANUFACTURING PLANNING

A. Parts-Material Requirements

The Parts-Material Requirements File provides an up-to-date record of the material description and quantity required to make a company designed part. The file originates from the Engineering description of the Bill of Material. Both material descriptions and quantity required are later refined to meet production planning requirements.

The Parts-Material Requirements record is created at the same time that the original Engineering document is reviewed by the Data Release Group for Engineering Assembly Parts List information. At this time the material description is matched against the Material Code Catalog, and the material code number and unit of measure is applied to the part number. Manufacturing Data Release reviews the latest manufacturing planning and revises the Parts-Material Requirements to reflect the planned material requirements.

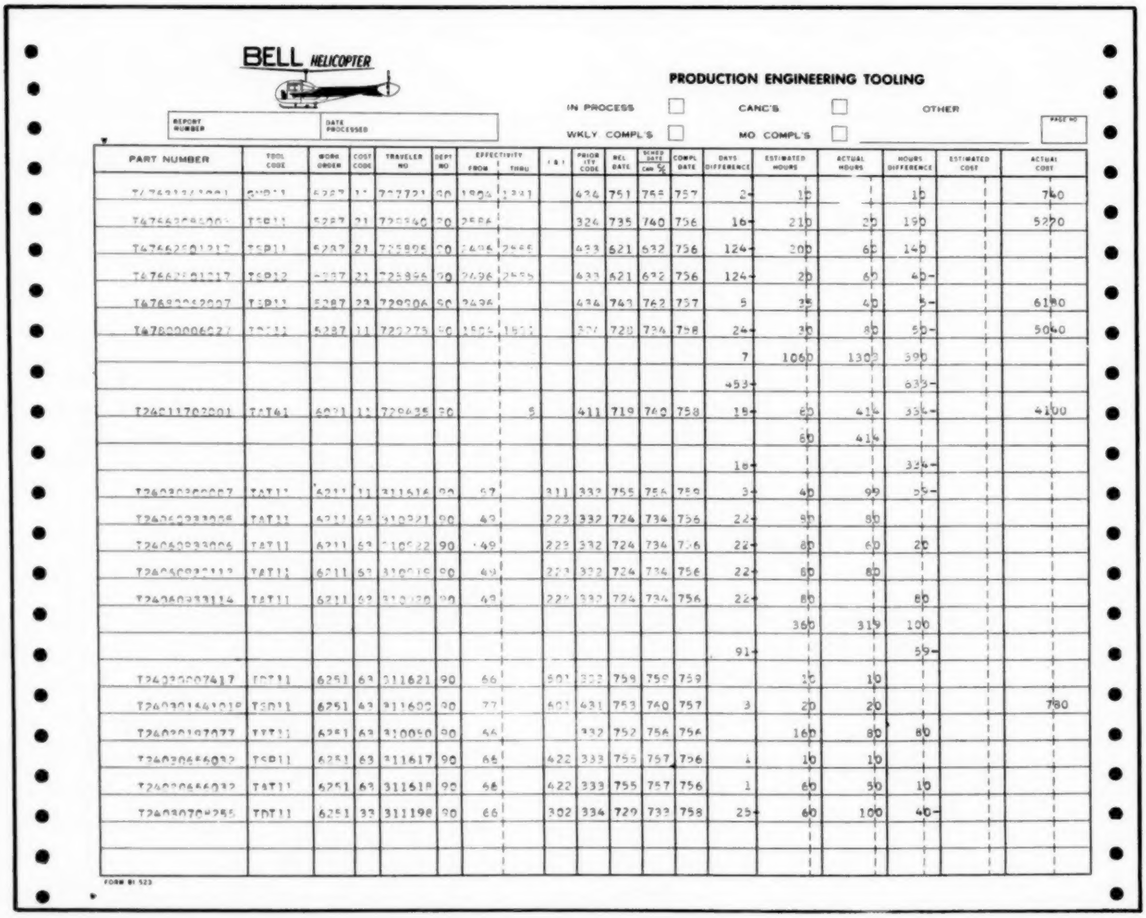
The Parts-Material Requirements File is used as input data for the computer program for raw material requirements. It also provides a media for compiling the contractual Bill of Material for the Military and for arriving at other statistical information relating to materials.

B. Parts-Tool Requirements

The Parts-Tool Requirement List provides a method by which a family of tools can be directly related to the part or parts on which they are used.

The Data Release Group sets up this file in conjunction with the review of manufacturing planning which is performed to update the Manufacturing Assembly Parts List. All tools, made or subcontracted, are recorded to reflect their relationship to the planned manufacturing sequence.

The Parts-Tool Requirements File used with the Tooling Order Location File will reflect the location of those tools used to produce parts that have been cancelled or stopped by Engineering. The family of tools, that is to be delivered to a vendor because of a switch in the make or buy status of the parts, can be identified, located and expedited in a short period of time.



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PRODUCTION ENGINEERING TOOLING

REPORT NUMBER | DATE PROCESSED

IN PROCESS ☐ CANC'S ☐ OTHER

WKLY COMPL'S ☐ MO COMPL'S ☐

PAGE NO

PART NUMBER	TOOL CODE	WORK ORDER	COST CODE	TRAVELER NO	DEPT NO	EFFECTIVITY FROM	EFFECTIVITY THRU	(&)	PRIORITY CODE	REL DATE	SCHED DATE CAN SC	COMPL DATE	DAYS DIFFERENCE	ESTIMATED HOURS	ACTUAL HOURS	HOURS DIFFERENCE	ESTIMATED COST	ACTUAL COST
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	90	1904	[illegible]		434	751	755	757	2-	10		10		740
T4766[illegible]	TSP11	5287	21	[illegible]	90	[illegible]			324	735	740	756	16-	210	20	190		5270
T47662[illegible]01217	TSP11	5287	21	725895	90	2496	[illegible]		433	621	632	756	124-	200	60	140		
T47662[illegible]01217	TSP12	[illegible]	21	725896	90	2496	[illegible]		433	621	632	756	124-	20	60	40-		
T4768[illegible]2007	TSP11	5287	23	729906	90	2434			434	743	762	757	5	35	40	5-		6180
T47800006027	[illegible]	5287	11	722275	90	1504	[illegible]		[illegible]	720	734	758	24-	30	80	50-		5040
													7	1060	1303	590		
													453-			633-		
T24011702001	TAT41	6021	11	729435	90		5		411	719	740	758	15-	60	414	354-		4100
														60	414			
													16-			354-		
T240[illegible]7	TAT11	6211	11	311616	90	57		311	332	755	756	759	3-	40	99	59-		
T2406[illegible]	TAT11	6211	63	310321	90	49		223	332	724	734	756	22-	90	80			
T24060933006	TAT11	6211	63	[illegible]	90	49		223	332	724	734	756	22-	80	60	20		
T240[illegible]	TAT11	6211	63	[illegible]	90	49		223	332	724	734	756	22-	80	80			
T24060933114	TAT11	6211	63	[illegible]	90	49		223	332	724	734	756	22-	80		80		
														360	319	100		
													91-			59-		
T240[illegible]07417	[illegible]	6251	63	311621	90	66		501	[illegible]	759	759	759		10	10			
T240[illegible]	TSD11	6251	63	[illegible]	90	77		601	431	753	760	757	3	20	20			780
T240[illegible]07077	[illegible]	6251	63	310050	90	66			332	752	756	756		160	80	80		
T24030[illegible]6032	TSP11	6251	63	311617	90	66		422	333	755	757	756	1	10	10			
T240[illegible]6032	TAT11	6251	63	311618	90	68		422	333	755	757	756	1	60	50	10		
T24030[illegible]255	TDT11	6251	33	311198	90	66		302	334	729	733	758	25-	60	100	40-		

FORM BI 523

VI. TOOL CONTROL

A. Tool Control Objective

The prime objective is to provide current information concerning the status of tools in process as well as historical information on tools completed.

B. Reporting and Control System

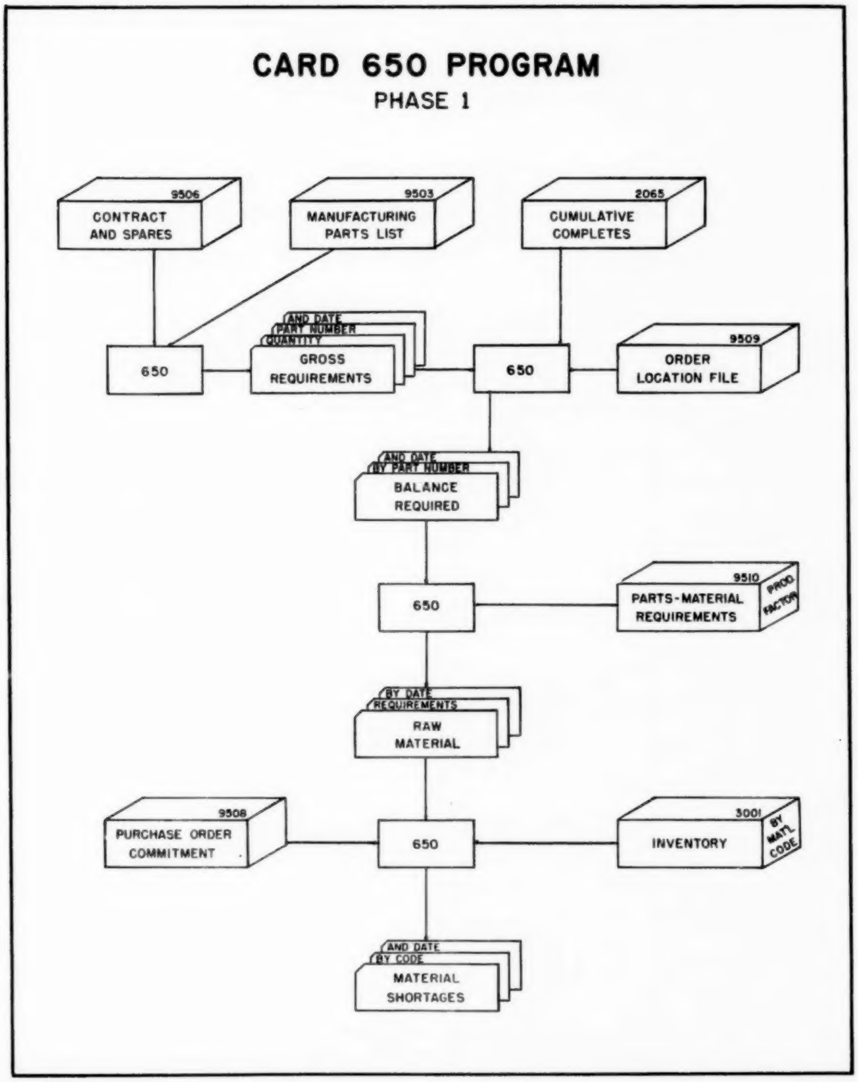
The basis for all reports is a Master Tool File. This file is established from a copy of the tooling order authorizing the tool. As labor cards are received daily, Data Processing updates the master file to reflect total hours expended.

Regular reports are prepared weekly to provide the following information:

1. Work-in-process - Hours expended to date compared to estimated standard
2. Completions - Total hours and comparison of actual to schedule completion date
3. Exemptions
   a. Inactive - No labor charge in past 20 days or 20 days since release with no activity
   b. Mis-Charges - Usually indicating errors in recording time charged to work

C. Usage

Experience has shown the Work-in Process Report to be quite valuable as a tool in shop loading and in forecasting tool completion dates. Completion Reports provide historical data which is utilized in making future estimates of tool costs and schedules. The over-all knowledge gained from these timely and accurate reports allows greater confidence to be placed in planning for the usage of the completed tools.



CARD 650 PROGRAM

PHASE 1

9506
CONTRACT AND SPARES
9503
MANUFACTURING PARTS LIST
2065
CUMULATIVE COMPLETES
650
AND DATE
PART NUMBER
QUANTITY
GROSS REQUIREMENTS
650
9509
ORDER LOCATION FILE
AND DATE
BY PART NUMBER
BALANCE REQUIRED
650
9510
PARTS-MATERIAL REQUIREMENTS
PROD. FACTOR
BY DATE
REQUIREMENTS
RAW MATERIAL
9508
PURCHASE ORDER COMMITMENT
650
3001
INVENTORY
BY MAT'L CODE
AND DATE
BY CODE
MATERIAL SHORTAGES

VII. PRODUCTION CONTROL AND MATERIAL CONTROL

A. Production Control

The objective of Production Control is to schedule and release the parts required to manufacture the end product. This is accomplished through the continuous comparison between planned and actual results.

The Gross Requirements computer program, developed through the use of the Contract and Spares Data and the Manufacturing Assembly Parts List, computes and schedules the planned requirements by part number. The actual results, Cumulative Completes (completed parts) and Order Location file (work-in-process), compared and subtracted from the planned Gross Requirements produce the scheduled Balance Required by part number.

The program as outlined on the master chart will be incorporated at a later date. Standard times are not now available and as a result certain interim procedures have been set into motion, substituting the Order Location File for an actual location file based upon move-tickets and average manufacturing flow times for detail schedules.

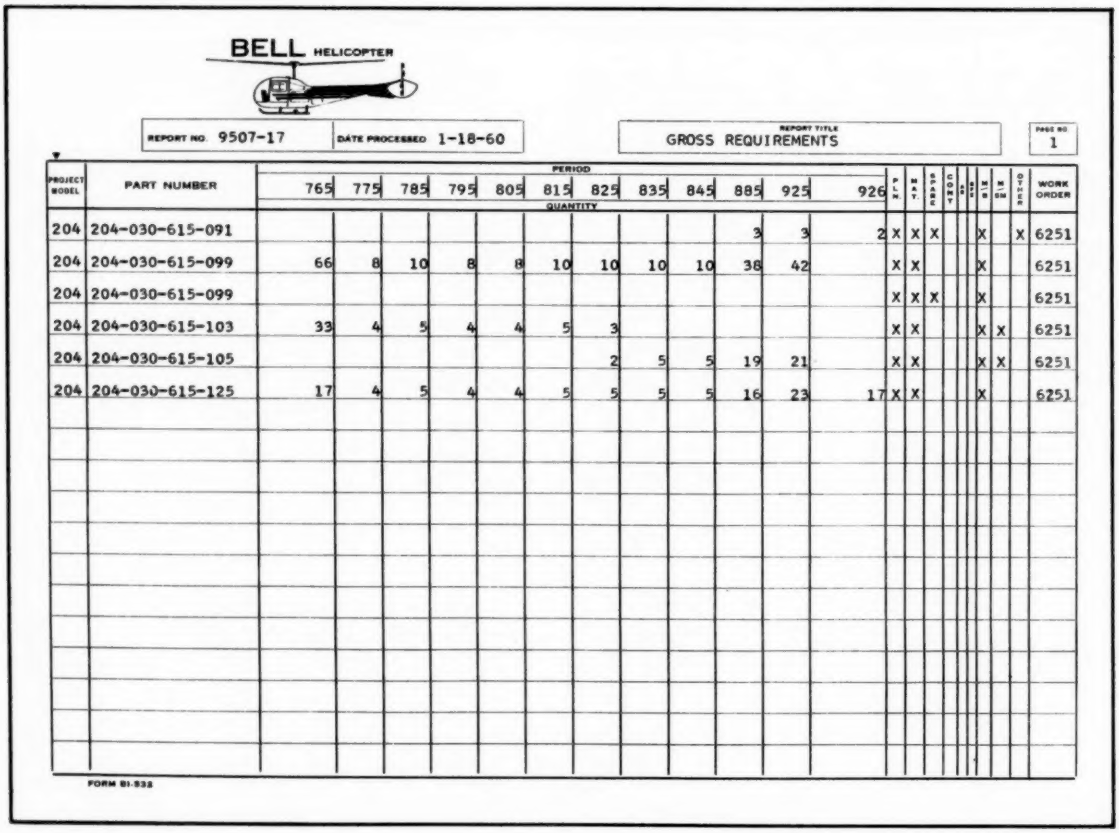
Production Control will be effective in proportion to the accuracy of observation of every definite step in the series of changes that affect parts and material as to quantity, quality and schedule.

B. Material Control

The purpose of Material Control is to provide the required quantity and quality of material at the required time and place with the minimum feasible investment.

The Balance Required by part number is converted to material codes through the use of the Parts-Material Requirement File. The quantity of parts is converted to amount of material which is factored for scrap and material loss allowances. This results in the scheduled Raw Material Requirements by material code. The Raw Material Requirements, minus the Inventory coverage and Purchase Order Commitments, are the scheduled Material Shortages by material code.

The functions of Material Control are determining probable material requirements, securing an adequate supply on time, recording all stores transactions on suitable records and furnishing the data for cost and financial accounting.



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REPORT NO. 9507-17 DATE PROCESSED 1-18-60

REPORT TITLE GROSS REQUIREMENTS

PAGE NO. 1

PROJECT MODEL	PART NUMBER	PERIOD												PLN.	MAT.	SPARE	CONT	[illegible]	[illegible]	M/B	M/SM	OTHER	WORK ORDER
		765	775	785	795	805	815	825	835	845	885	925	926										
		QUANTITY																					
204	204-030-615-091										3	3	2	X	X	X				X		X	6251
204	204-030-615-099	66	8	10	8	8	10	10	10	10	38	42		X	X					X			6251
204	204-030-615-099													X	X	X				X			6251
204	204-030-615-103	33	4	5	4	4	5	3						X	X					X	X		6251
204	204-030-615-105							2	5	5	19	21		X	X					X	X		6251
204	204-030-615-125	17	4	5	4	4	5	5	5	5	16	23	17	X	X					X			6251

FORM 81-532

VIII. GROSS REQUIREMENTS

A. Source Data

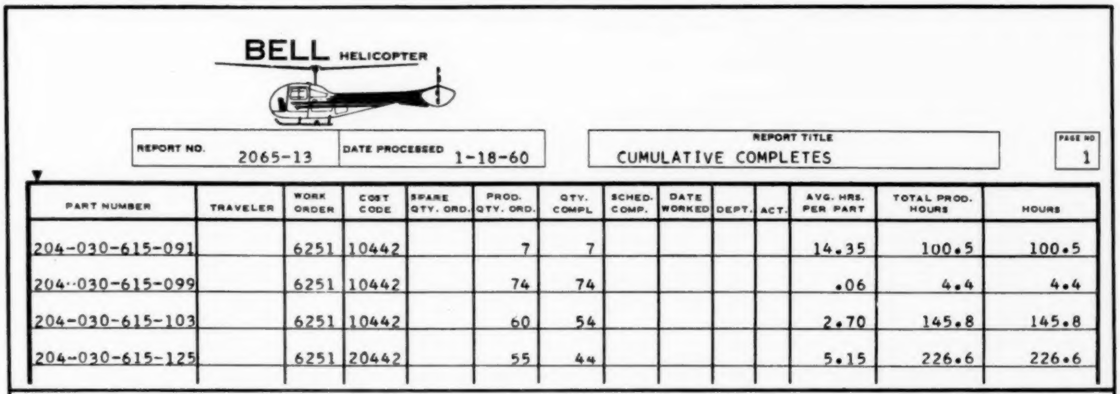
Gross Requirements is a system that coordinates the Manufacturing Assembly Parts List, the Contract and Spares obligations, Item and Indenture data and the scheduling factor (Time Period Table) into a computer routine that produces as output the scheduled gross requirement of parts and assemblies.

B. Functions of Computer Program

1. The ship contract cards are stored in the computer and the spares assembly requirements are merged in front of their respective assembly breakdowns in the Manufacturing Assembly Parts List.
2. Item and Indenture and Time Period data are stored in the computer.
3. As the first parts card is read into the computer, a table look-up is performed to find the applicable contract to get the quantity and M-day delivery of that ship. The quantity in the parts card is extended by the contract quantity. Using the item and indenture of the parts card, a table look-up is performed to determine the number of days required for setback, which is subtracted from the ship's delivery date. This net M-day is used to perform another table look-up to find the applicable period in the Time Period Table and store the quantity required in this period. At this point in the program, a test is made for the end of thhe parts efficiency. If the efficiency continues, this procedure is repeated as many times as needed until it is determined that this part is no longer effective. A requirement card is punched into the gross requirements format, spreading the quantities by period, and punching codes for the following: type of part, raw material requirement, spares or ship requirement and make or buy. At the end of this loop, another parts card is read. This will continue until the complete Manufacturing Assembly Parts List has been passed through the computer.

C. Usage

Gross Requirements is performed to establish the basic data for continuous comparison between the planned and the actual results.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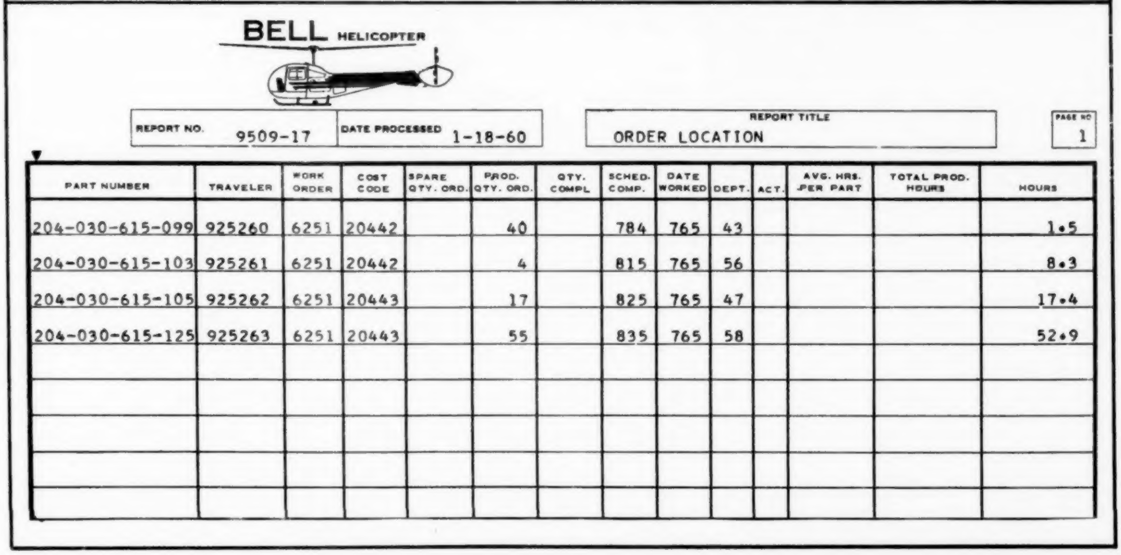
REPORT NO. 2065-13 | DATE PROCESSED 1-18-60 | REPORT TITLE CUMULATIVE COMPLETES | PAGE NO 1

PART NUMBER	TRAVELER	WORK ORDER	COST CODE	SPARE QTY. ORD.	PROD. QTY. ORD.	QTY. COMPL	SCHED. COMP.	DATE WORKED	DEPT.	ACT.	AVG. HRS. PER PART	TOTAL PROD. HOURS	HOURS
204-030-615-091		6251	10442		7	7					14.35	100.5	100.5
204-030-615-099		6251	10442		74	74					.06	4.4	4.4
204-030-615-103		6251	10442		60	54					2.70	145.8	145.8
204-030-615-125		6251	20442		55	44					5.15	226.6	226.6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REPORT NO. 9509-17 | DATE PROCESSED 1-18-60 | REPORT TITLE ORDER LOCATION | PAGE NO 1

PART NUMBER	TRAVELER	WORK ORDER	COST CODE	SPARE QTY. ORD.	PROD. QTY. ORD.	QTY. COMPL	SCHED. COMP.	DATE WORKED	DEPT.	ACT.	AVG. HRS. PER PART	TOTAL PROD. HOURS	HOURS
204-030-615-099	925260	6251	20442		40		784	765	43				1.5
204-030-615-103	925261	6251	20442		4		815	765	56				8.3
204-030-615-105	925262	6251	20443		17		825	765	47				17.4
204-030-615-125	925263	6251	20443		55		835	765	58				52.9

IX. NET-PARTS REQUIREMENTS

A. Source Data

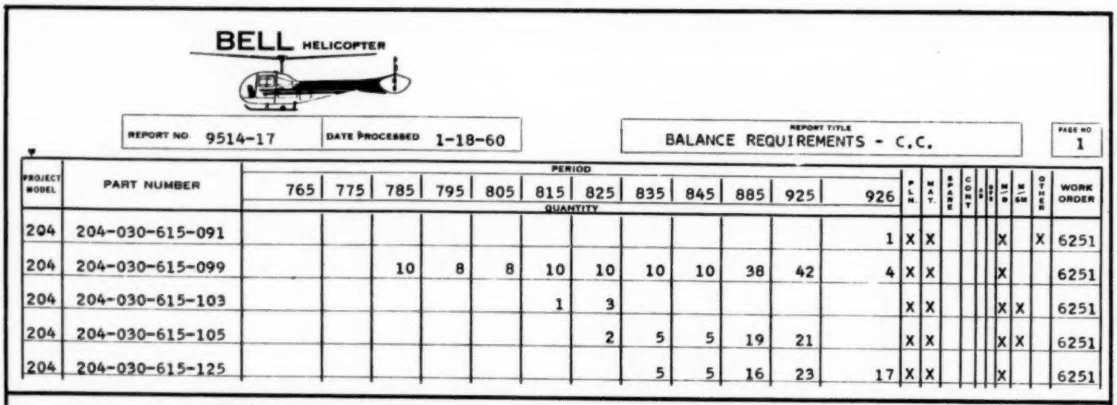
Net-Parts Requirements consist of the source data required to fulfill the necessary and continuous comparison between the planned and actual results. The data is comprised of the Cumulative Completes file and the Order Location file. Both files are based upon information derived from shop travelers.

1. Traveler - A shop traveler is the authorization to commence production. The traveler furnishes basic information such as part number, traveler serial number, work order, quantity and scheduled release and completion dates.
2. Cumulative Completes - The Cumulative Completes file is set up to capture the total completed parts by part number through the recording of completed travelers. This is accomplished by routing the completed traveler through Data Processing where the pertinent information is punched into tab cards. The means of measuring contract progress, reducing shop load, establishing parts cost and Balance Required are available through various techniques applied to this file.
3. Order Location - The Order Location file has in it a card for every type of shop traveler (production, rework, inspection and split) that is in process. The quantities in these cards are updated daily by scrap notices, split travelers, lost parts requisitions and material disposition reports. The location of the travelers is constantly changing and this action is reflected by last reported labor. A review of this file would reflect the latest location and status of each traveler in the shop.

B. Usage

When preparations are complete and engineering standard times are available, the Order Location File will be the primary means used to establish an accurate Shop Load Report.

The Cumulative Completes and Order Location files are maintained daily to provide the current status of parts and travelers. This information being readily available provides management with last reported labor. A review of this file would decisions.



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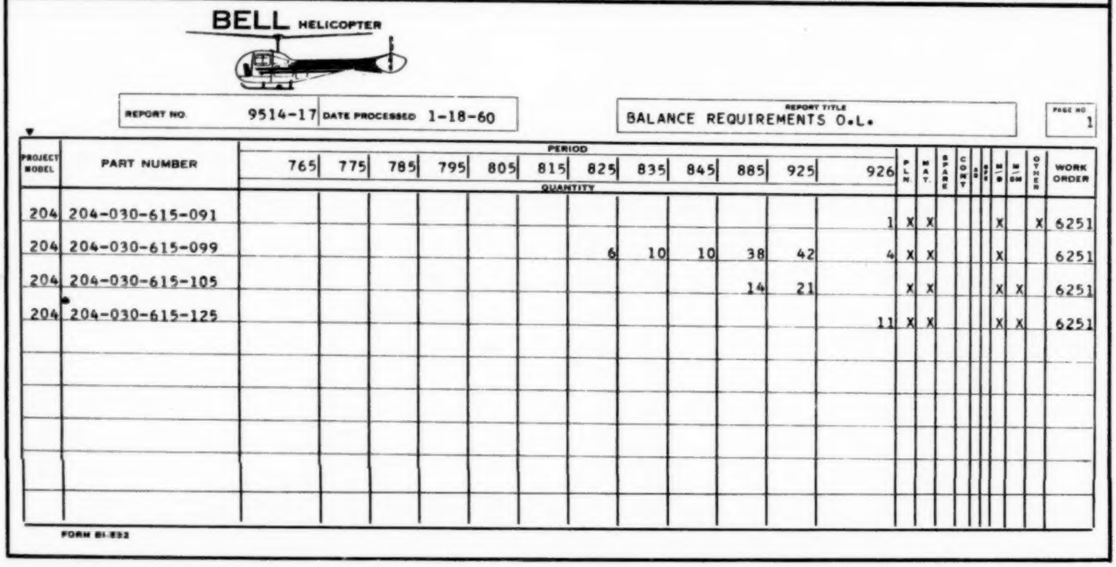
REPORT NO 9514-17 DATE PROCESSED 1-18-60

REPORT TITLE BALANCE REQUIREMENTS - C.C.

PAGE NO 1

PROJECT MODEL	PART NUMBER	PERIOD												PLN.	MAT.	SPARE	CONT	[illegible]	[illegible]	M/D	M/SM	OTHER	WORK ORDER
		765	775	785	795	805	815	825	835	845	885	925	926										
		QUANTITY																					
204	204-030-615-091												1	X	X					X		X	6251
204	204-030-615-099			10	8	8	10	10	10	10	38	42	4	X	X					X			6251
204	204-030-615-103						1	3						X	X					X	X		6251
204	204-030-615-105							2	5	5	19	21		X	X					X	X		6251
204	204-030-615-125								5	5	16	23	17	X	X					X			6251



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REPORT NO 9514-17 DATE PROCESSED 1-18-60

REPORT TITLE BALANCE REQUIREMENTS O.L.

PAGE NO 1

PROJECT MODEL	PART NUMBER	PERIOD												PLN.	MAT.	SPARE	CONT	[illegible]	[illegible]	M/D	M/SM	OTHER	WORK ORDER
		765	775	785	795	805	815	825	835	845	885	925	926										
		QUANTITY																					
204	204-030-615-091												1	X	X					X		X	6251
204	204-030-615-099							6	10	10	38	42	4	X	X					X			6251
204	204-030-615-105										14	21		X	X					X	X		6251
204	204-030-615-125												11	X	X					X	X		6251

FORM BI-832

X. BALANCE REQUIRED

A. Source Data

Balance Required is the system developed to measure the actual status of part requirements against the planned part requirements to arrive at the balance of parts required to meet the contractual obligations. The data necessary to fulfill this system follows:

1. Gross Requirements - Planned requirements by part number
2. Cumulative Completes - Actual completions by part number
3. Order Location - Actual status of in-process travelers by part number

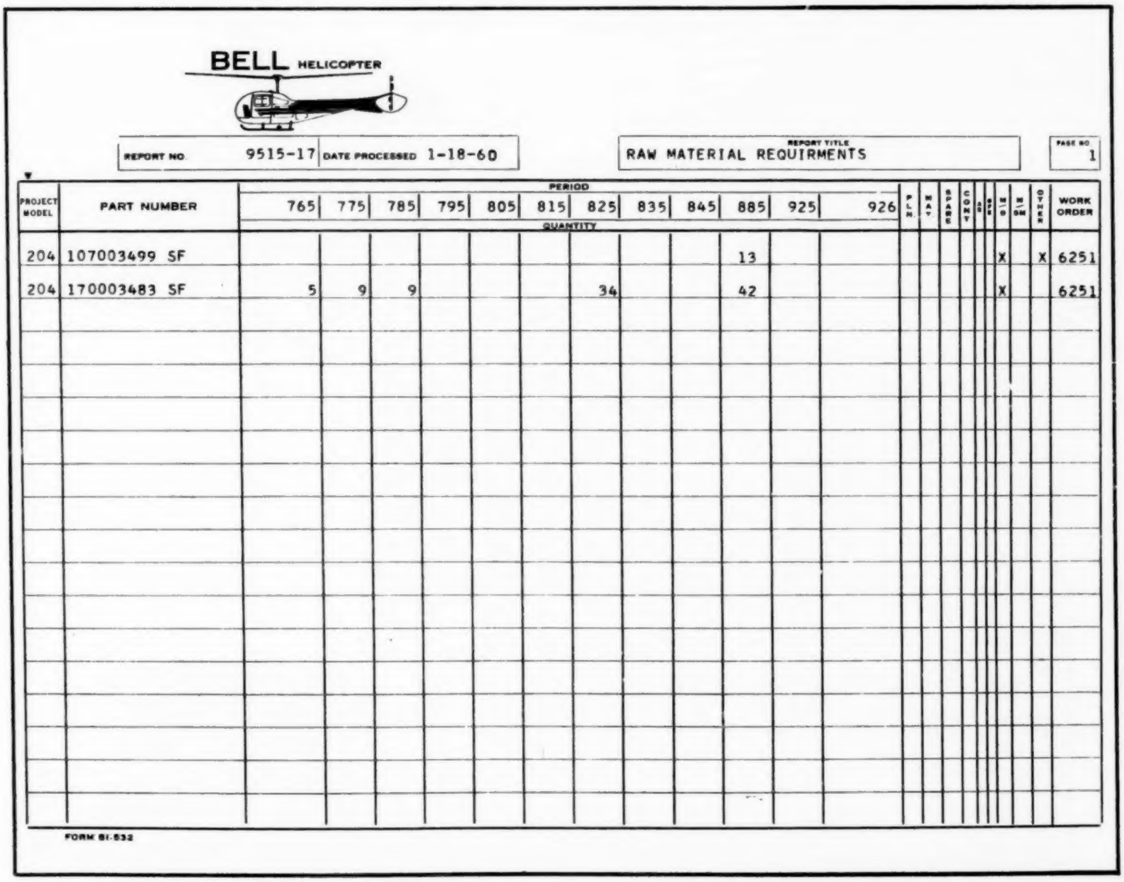
The Gross Requirements is merged with the Cumulative Completes and Order Location Files by part number.

B. Functions of Computer Program

1. Completed parts are subtracted from Gross Requirements, period by period, beginning with the behind schedule requirement.
2. In-process parts are subtracted from the balance of Gross Requirements, period by period, beginning with the first period having a requirement not fulfilled by completed parts.
3. A Balance Required card is punched, reflecting the balance of parts, by period, yet to be manufactured.
4. Stock shortage notices are punched if sufficient parts have not been completed to meet the requirement in the behind schedule period.
5. Traveler expedite notices are punched as a result of stock shortage, recommending the traveler with the least amount of work remaining to finish the parts.
6. Excess stock notices are punched as a result of completed parts and work-in-process being over the contract requirements.
7. Traveler stop notices are punched as a result of excess stock.

C. Usage

The Balance Required data is readily put to use in Production Control, Dispatching, the Production Office and at the Warehouse to establish more effective controls over part requirements.



BELL HELICOPTER

REPORT NO. 9515-17 DATE PROCESSED 1-18-60

REPORT TITLE RAW MATERIAL REQUIRMENTS

PAGE NO 1

PROJECT MODEL	PART NUMBER	PERIOD 765	775	785	795	805	815	825	835	845	885	925	926	PLN.	MAT.	SPARE	CONT	AS	GFE	M/O	M/SM	OTHER	WORK ORDER
		QUANTITY																					
204	107003499 SF										13									X		X	6251
204	170003483 SF	5	9	9				34			42									X			6251

FORM 81-532

XI. RAW MATERIAL REQUIREMENTS

A. Source Data

The purpose of the Raw Material Requirements System is to convert part number requirements to raw material requirements, thereby providing the basic data needed to enable Material Control to furnish the required quantity and quality of material at the required time.

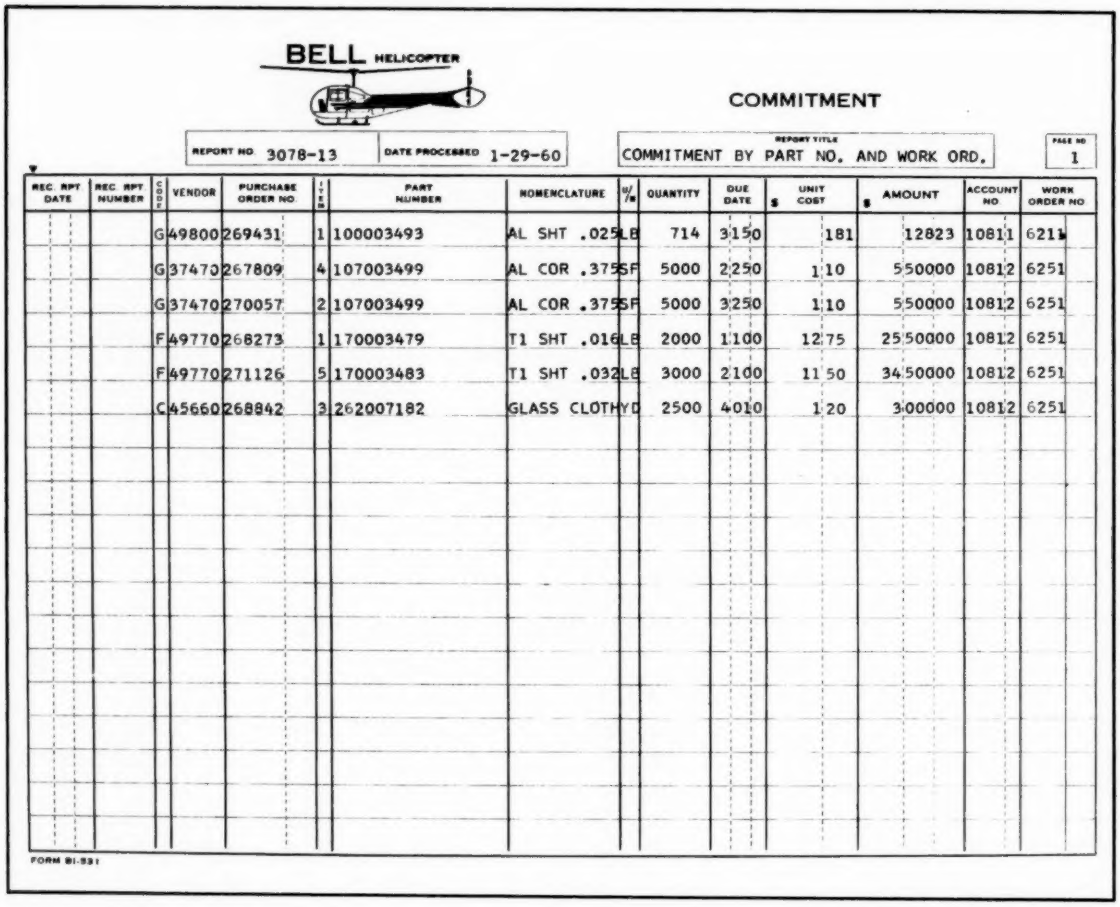
1. Balance Required - Balance of planned requirements by part number
2. Parts-Material Requirements - Material data by part number

B. Function of Computer Program

The computer routine is programmed to convert part numbers to material codes, compute the amount of material required, factor the amount of material by the scrap and material loss allowance, adjust the schedule by the average manufacturing flow times thereby reflecting the actual material requirement date and to punch the raw material requirement card. The average manufacturing flow times result from the Type of Part coding used in the Manufacturing Assembly Parts List and carried through for just this action.

C. Usage

The Raw Material Requirements System defines the material requirements yet to be fulfilled from inventory. These material requirements will proceed through the Material Shortage System as the planned requirements needed to establish material shortages.



BELL HELICOPTER

COMMITMENT

REPORT NO. 3078-13 | DATE PROCESSED 1-29-60

REPORT TITLE COMMITMENT BY PART NO. AND WORK ORD.

PAGE NO 1

REC. RPT DATE	REC. RPT NUMBER	CODE	VENDOR	PURCHASE ORDER NO.	ITEM	PART NUMBER	NOMENCLATURE	U/M	QUANTITY	DUE DATE	$ UNIT COST	$ AMOUNT	ACCOUNT NO	WORK ORDER NO
		G	49800	269431	1	100003493	AL SHT .025	LB	714	3150	181	12823	10811	6211
		G	37470	267809	4	107003499	AL COR .375	SF	5000	2250	110	550000	10812	6251
		G	37470	270057	2	107003499	AL COR .375	SF	5000	3250	110	550000	10812	6251
		F	49770	268273	1	170003479	T1 SHT .016	LB	2000	1100	1275	2550000	10812	6251
		F	49770	271126	5	170003483	T1 SHT .032	LB	3000	2100	1150	3450000	10812	6251
		C	45660	268842	3	262007182	GLASS CLOTH	YD	2500	4010	120	300000	10812	6251

FORM BI-531

XII. PURCHASE ORDER COMMITMENT

A. Purpose of Commitment File

The Purchase Order Commitment File contains all of the necessary data to completely describe the company's outstanding obligations in regard to purchased items that are on order.

B. File Contents

All of the information for the commitment file is extracted directly from a single source document, a copy of the purchase order. The file contains:

1. Purchase Order and Buyer Number
2. Vendor Identification
3. Description of purchased item including material code
4. Quantity, Unit Cost and Extended Value
5. Due Date for purchased items
6. Identification to Account and Work Order (Contract)

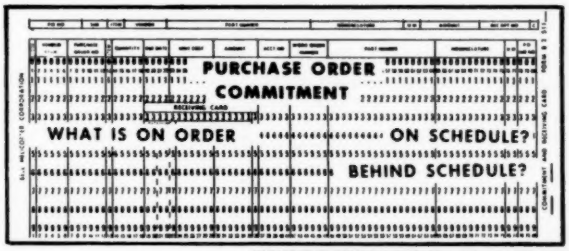
C. File Maintenance

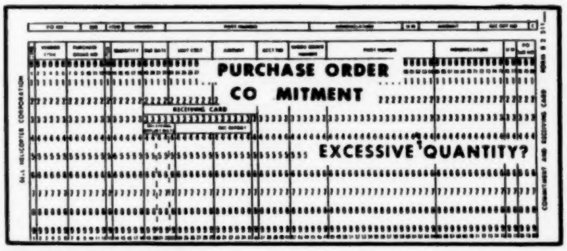
The files are updated daily, providing for information in the file concurrent with the issue of the purchase order to the vendor. The file is relieved daily upon receipt of a copy of the receiving report Information on the receiving document is also used to update the inventory files.

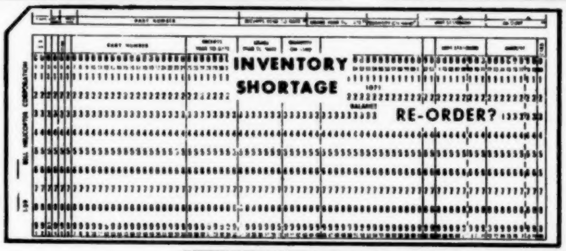
D. Commitment File Usage

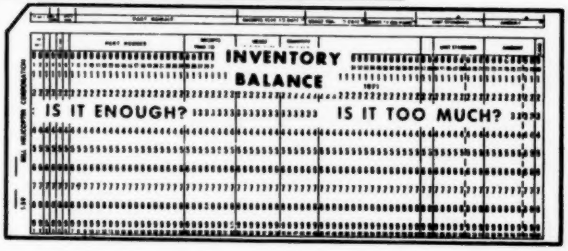
The prime usage of the Purchase Order Commitment file is to fulfill control requirements for Material and Accounting Departments.

1. Material Control
   a. Highlight actual delinquent receipt of materials
   b. Highlight potential schedule delinquents
   c. Internal Procurement reports by buyer, etc.
2. Accounting Control
   a. Forecast of cash requirements by periods
   b. Budgets by work order (contract)
   c. Internal financial control

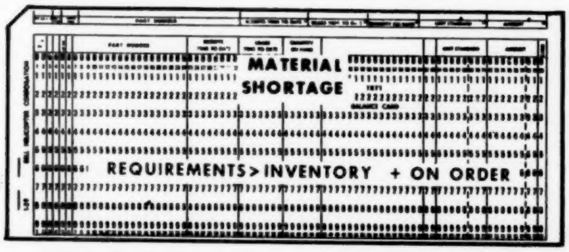

PURCHASE ORDER
COMMITMENT
RECEIVING CARD
WHAT IS ON ORDER
ON SCHEDULE?
BEHIND SCHEDULE?
BELL HELICOPTER CORPORATION
COMMITMENT AND RECEIVING CARD


PURCHASE ORDER
CO MITMENT
RECEIVING CARD
EXCESSIVE QUANTITY?
BELL HELICOPTER CORPORATION
COMMITMENT AND RECEIVING CARD


INVENTORY
SHORTAGE
RE-ORDER?
BELL HELICOPTER CORPORATION


INVENTORY
BALANCE
IS IT ENOUGH?
IS IT TOO MUCH?
BELL HELICOPTER CORPORATION

650
OUTPUT


MATERIAL
SHORTAGE
BALANCE CARD
REQUIREMENTS > INVENTORY + ON ORDER
BELL HELICOPTER CORPORATION

XIII. MATERIAL SHORTAGES

A. General Input and Output

The Raw Material Requirements Output, Purchase Order Commitment and Inventory Files are combined to establish material shortages. In addition to supplying the necessary data for this program, the Inventory File fulfills the requirements of the Accounting Department.

In determining material shortages or overages, the net material requirements (output from Raw Material Computer Program) is compared to inventory and purchase order commitments through a computer program.

B. Program Objectives

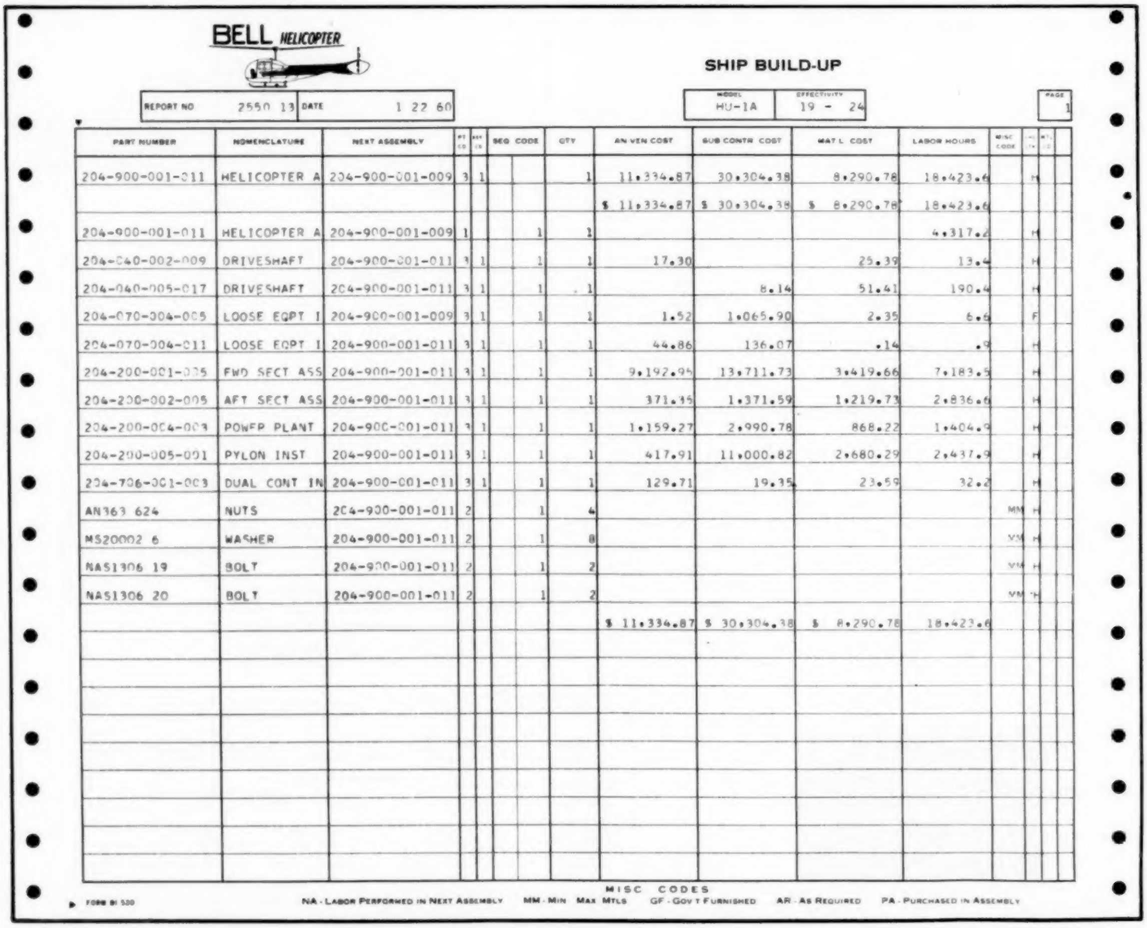
The objective of the program is to advise when inventory balance will not meet immediate requirements and/or when inventory plus "open" purchase orders will not meet future requirements. In Addition, excessive inventories and/or "open" purchase order quantities must be recognized. To provide this information, the following output from the computer program is required.

1. Inventory Balance
2. Inventory Shortage
3. Purchase Order Commitments - Behind Schedule
4. Purchase Order Commitments - Excessive Quantities
5. Material Shortages

C. General Usage of Data

With the reports generated from this output the following action is taken:

1. Excessive inventory balances screened by Production Control for disposition.
2. Shortages reviewed for corrective action.
3. Purchasing reviewed for possible re-schedule of delinquent items to meet requirements.
4. Purchasing review for excessive quantities on order.



BELL HELICOPTER

SHIP BUILD-UP

REPORT NO 2550 13 DATE 1 22 60

MODEL HU-1A EFFECTIVITY 19 - 24 PAGE 1

PART NUMBER	NOMENCLATURE	NEXT ASSEMBLY	PT CD	[illegible]	SEQ CODE		QTY	AN VEN COST	SUB CONTR COST	MAT'L COST	LABOR HOURS	MISC CODE	[illegible]	[illegible]	
204-900-001-011	HELICOPTER A	204-900-001-009	3	1			1	11.334.87	30.304.38	8.290.78	18.423.6		H		
								$ 11.334.87	$ 30.304.38	$ 8.290.78	18.423.6				
204-900-001-011	HELICOPTER A	204-900-001-009	1			1	1				4.317.2		H		
204-040-002-009	DRIVESHAFT	204-900-001-011	3	1		1	1	17.30		25.39	13.4		H		
204-040-005-017	DRIVESHAFT	204-900-001-011	3	1		1	1		8.14	51.41	190.4		H		
204-070-004-005	LOOSE EQPT I	204-900-001-009	3	1		1	1	1.52	1.065.90	2.35	6.6		F		
204-070-004-011	LOOSE EQPT I	204-900-001-011	3	1		1	1	44.86	136.07	.14	.9		H		
204-200-001-005	FWD SECT ASS	204-900-001-011	3	1		1	1	9.192.95	13.711.73	3.419.66	7.183.5		H		
204-200-002-005	AFT SECT ASS	204-900-001-011	3	1		1	1	371.35	1.371.59	1.219.73	2.836.6		H		
204-200-004-003	POWER PLANT	204-900-001-011	3	1		1	1	1.159.27	2.990.78	868.22	1.404.9		H		
204-200-005-001	PYLON INST	204-900-001-011	3	1		1	1	417.91	11.000.82	2.680.29	2.437.9		H		
204-706-001-003	DUAL CONT IN	204-900-001-011	3	1		1	1	129.71	19.35	23.59	32.2		H		
AN363 624	NUTS	204-900-001-011	2			1	4					MM	H		
MS20002 6	WASHER	204-900-001-011	2			1	8					MM	H		
NAS1306 19	BOLT	204-900-001-011	2			1	2					MM	H		
NAS1306 20	BOLT	204-900-001-011	2			1	2					MM	H		
								$ 11.334.87	$ 30.304.38	$ 8.290.78	18.423.6				

FORM BI 530

MISC CODES

NA - Labor Performed in Next Assembly MM - Min Max Mtls GF - Gov't Furnished AR - As Required PA - Purchased in Assembly

XIV. SHIP BUILD-UP

A. Source Data

The Ship Build-Up may be defined as a priced Bill of Material.

The Bill of Material is a complete Engineering drawing breakdown which is coded to produce a "Christmas Tree" type of breakdown. All Engineering changes are reflected in the Bill of Material as they are released.

The cost information used in evaluating the Bill of Material is obtained as by-products of other Data Processing applications.

The source of the four basic costs are:

1. Labor for manufactured parts is extracted from labor distribution.
2. Raw material cost is furnished through stores requisitions and other inventory activity.
3. Cost of Subcontracted parts is available through Accounts Payable disbursements.
4. Cost of Standard and Commercial parts is also furnished by Accounts Payable data.

B. Computer Program

Although the Bill of Material consists of 17,000 parts, a unique computer program "tells the story" in two hours. In this time the costs are applied to the Bill of Material to produce total value of the end item from the smallest component to the finished product.

C. Usage

The Ship Build-Up program is used for the following:

1. Measure performance or costs against negotiated costs.
2. Projection from current costs to a basis for future proposals.
3. Price redetermination.
4. Preparation of spare parts exhibits.

section 5

SOLID ROCKET PRODUCTION — A LOOK TO THE FUTURE

by **RAOUL S. DOBYNS**
General Supervisor

OPERATIONS & METHODS
NORTH AMERICAN AVIATION, INC.

Mr. Dobyns received his Bachelor of Industrial Engineering degree in 1947 from the University of Florida. In 1951 his alma mater awarded him the professional degree, Industrial Engineer, in recognition of professional accomplishment.

As Lt. Colonel in the U. S. Air Force Reserve, Mr. Dobyns served in a number of assignments since World War II within the Air Materiel Command. His last military assignment was as Inspector General of the Southern Air Procurement District in Fort Worth, Texas.

In 1953, Mr. Dobyns joined the Rocket Fuels Division of Phillips Petroleum Company. He was appointed Manager of Industrial Engineering in 1956. Since the assimilation of that organization into North American Aviation, Inc., he has served as General Supervisor of Operations & Methods.

Mr. Dobyns is a registered professional engineer in Texas and Florida. He is a director and officer of the Central Texas Section of the American Rocket Society.

SOLID ROCKET PRODUCTION — A LOOK TO THE FUTURE

by RAOUL S. DOBYNS

General Supervisor, Operations & Methods; Solid Propulsion Operations,
Rocketdyne Division, North American Aviation, Inc.

SPACE TRAVEL AND ITS RELATED CHALLENGE

THE PAST few years have seen a phenomenal increase in the interest and effort directed toward space travel. We read every day of the intense world-wide competition to achieve space flight. Surely such a realm of man's activity will have its effect on all of us and may indeed see the Sixties as a Challenge to Industrial Engineering. In this presentation I would like to define for you a problem in a small segment of this large scientific and technological endeavor and tell you what is being done about it.

In terms of space travel, the concern of the next ten years will center around producing very large, high performance rocket motors. These engines, either singly or in multiple assemblies will serve to propel manned and unmanned missles, both military and scientific to the distant reaches of our solar system. In addition, the commercial use of missles will rapidly take shape with the development of transports, communication relay satellites, etc.

To keep the future in proper perspective, it is important to realize the rate at which the rocket engine has become one of the most important propulsion devices in our current cilivation, ranking with the engine-wheel and engine propeller combinations. The rocket engine has developed into two major categories in the past few years, the liquid and the solid motor. Although there are other modes of propulsion being added in what seems an endless variety (nuclear, ion, plasma, etc.), generally they have characteristics of low thrust and long duration and are not comparable to the two major divisions mentioned. It appears then that these two major divisions will be the all important ones of the next decade. The challenge we face in the Sixties is to learn how to produce both the solid and liquid engines in increasing size and thrust and at rates that approach mass production.

For purposes of this paper our discussion will be limited to the solid motor category. First, let me point out a few differences in these two types of propulsion systems. Differences which have a major effect on the techniques of mass production.

Essentially, the liquid engine is a mechanical device comprised of a number of pipes, pumps, components and controls, but fortunately, no more of a hazard on the production line than your automobile. Since all fuel and oxidizer can be added just prior to shipment (storable liquid types) or at the launch site under carefully controlled conditions, the production process is not unlike the building of aircraft. The solid motor presents a more difficult mass production problem in that it must be manufactured with all of its fuel and oxidizer ingredients in place. This casting or placing of the composite fuel oxidizer mass into position is the major part of the production process. In fact some propulsion systems today are not capable of supporting themselves structurally until they are so loaded.

Transporting a rocket motor on the roads and railroads across our nation is not a simple procedure. The large motors of the future, particularly those employing cast solid propellant, probably will require construction at the launch site. Clustered engines offer some advantages for factory fabrication of relatively small units with subsequent assembly at the launch site. However, it is important to note that the high reliability promised for the solid rocket motor may soon be sacrificed in a system requiring the proper simultaneous firing of a number of clustered units. The consensus tends to support a single large solid cast unit as the first stage solid propellant booster of the future. Sheer size and weight, not to mention the hazard of transporting a large mass of high energy propellant weighing several thousand pounds, seem to be adequate arguments for launch-site assembly.

As a result of the important place the rocket engine is to have in our future and because of factors such as those I have just reviewed, the solid rocket motor presents some production problems which will demand the best we can offer in fully automated and highly developed process techniques.

FUTURE REQUIREMENTS FOR SOLID PROPELLANT PRODUCTION

Examination of recent research papers indicates only a limited appreciation of the need for a true continuous production technique in producing large solid fueled rocket motors. In those few processes which do show promise, there remains a great deal of work to be done to adapt to automation in the pure sense. To be classed as "automated," a production process should lend itself inherently to automatic programming and direction in additon to expected features of mechanization. The majority of production methods currently in use for producing large solid propellant engines are based on the casting process and are "batch" in nature. As a result, they do not lend themselves to automation. This reluctance to automate in propellant production or more probably this reliance on proven techniques of the past may become a serious detriment in meeting the challenge previously defined. In the past decade solid propellant rocket motors have been quite small when compared with those now in development and soon to come. A large family of air to ground, air to air, ground to ground and ground to air missiles employing composit solid propellants has been developed to support and increase the firepower of our armed forces. The requirement at current levels of production for composite solid propellants established by these missiles has been appropriately satisfied by batch production techniques. Mixers of 300 to 350 gallons capacity, each preparing 3,600 to 4,200 pounds of propellant and operating in batteries were quite capable of satisfying a production run of missiles requiring 100 to 200 pounds of propellant each. Even the larger missiles, composed of several stages weighing 5,000 to 10,000 pounds each can be successfully produced in quantity by batch methods. However, the solid propellant requirements of the next ten years cannot be measured in such terms. The size of solid engines is increasing rapidly. Ten years ago a solid unit weighing 5,000 pounds was considered on the frontier of development. Today, we are perfecting units of 40,000 pounds of solid propellant and are predicting units of 3-1/2 million pounds by 1970, if we are to see moon landings and return by that time. The array of machinery of the conventional type (Figure 1) required to meet such outputs would require an investment of many millions of dollars and the production problems related to maintenance and quality assurance would be formidable. Size alone will dictate a new approach to solid rocket production. Currently, units 10 feet in diameter and 40 feet long are considered unwieldy to produce at one location and transport to the launching site. A unit 15 feet in diameter and 66 feet long is predicted for the foreseeable future. Such a unit, cast as a single stage, would provide about 2 million pounds of thrust, enough to launch a manned space station of 10 or 15 tons to a 1,000 mile altitude. Even the sizes are reduced in perspective when compared to some of the space giants near the end of the coming decade. A solid rocket motor of 10 million pounds thrust would measure approximately 20 feet in diameter and over 100 feet long. Although there are strong arguments for a cluster engine of this size, such a unit is entirely feasible. It would require fabrication and loading at the launch site. Figure 2 suggests how such a procedure might be carried out.

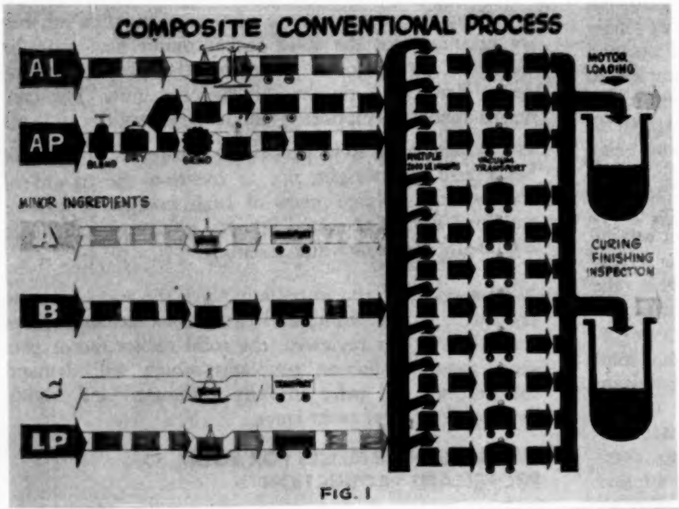


FIG. 1

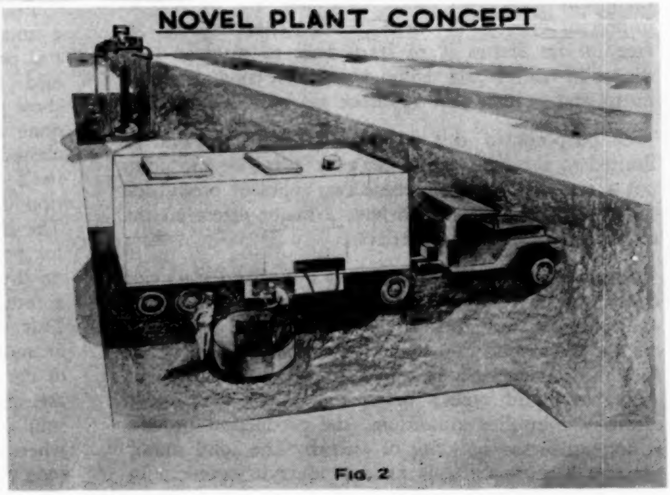


FIG. 2

PRESENT CAPABILITY TO TACKLE THE PROBLEM

The significance of the foregoing description of large solid rocket engines is best understood in terms of the pounds of propellant which must be produced in the coming ten years reflected against the requirements of the past ten years and our present ability to satisfy these production needs. Detailed figures cannot be released but are unnecessary to get a grasp of what is required. Figure 3 approximates what would be required of U.S. production if we are to successfully produce large solid rocket engines of the sizes previously mentioned. This is only a very rough approximation and is contingent on the successful development of a number of solid rocket motor projects which I have not mentioned. As previously pointed out, it appears the industry is going to to try to satisfy this increasing need for propellant production by a quasi-automated process. There are various versions currently under study but few of them show promise of more than mechanization or quite limited automation. In addition portability is somewhat neglected because of size and number of pieces of equipment necessary to form an integrated production plant. The element of portability becomes very important however when consideration is given to the fact that launch sites must be dispersed quite a bit if military rockets are concerned. Figure 4 depicts a highly portable plant in operation. Such a plant is currently under development. Figures 5 and 6 depict schematically a couple of the processes now under study in the industry. In analyzing these the reader should consider the size and cost of mixing equipment reflected against the yield per hour in pounds of propellant. Time to produce large quantities should also be considered in the light of casting a single unit or group of units weighing 3 million pounds. Something more than a "custom built" approach is needed if we are to meet the challange. The luxury we now enjoy of mixing a batch and checking quality standards by sampling methods designed to prove the

PREDICTED SOLID PROPELLANT REQUIREMENTS
MILITARY & OTHER

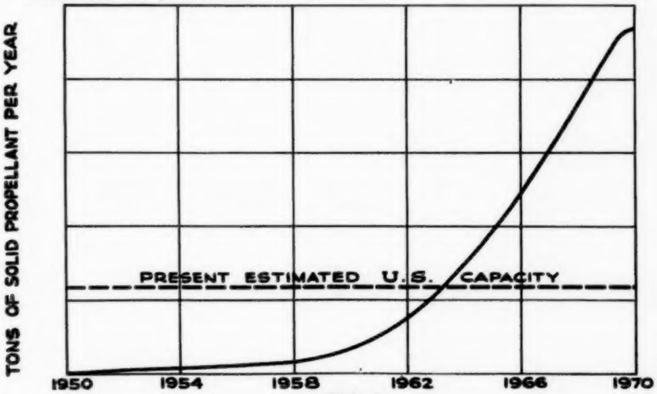


FIG. 3

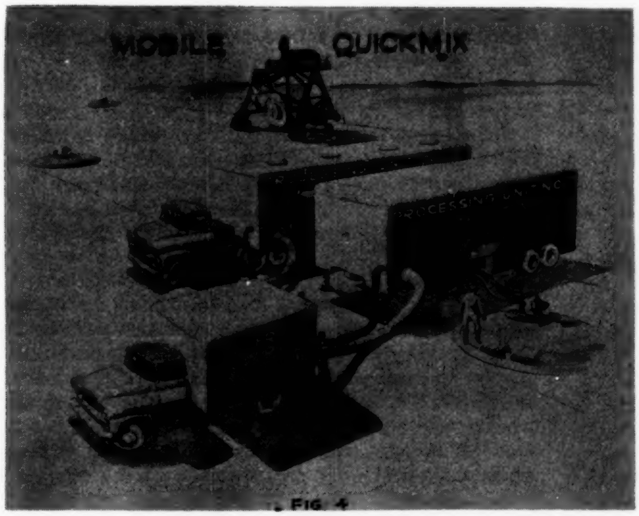


FIG. 4

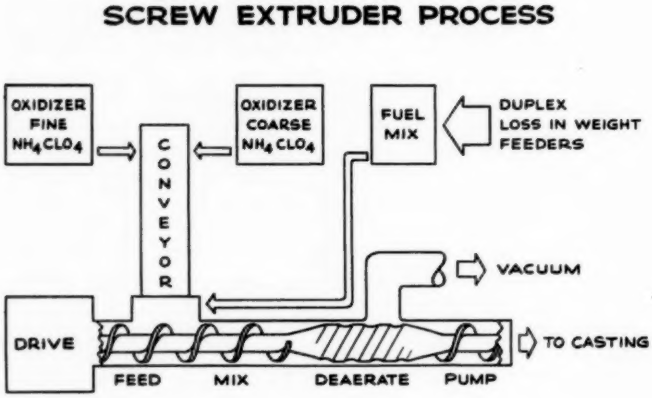

SCREW EXTRUDER PROCESS
OXIDIZER FINE NH4CLO4
CONVEYOR
OXIDIZER COARSE NH4CLO4
FUEL MIX
DUPLEX LOSS IN WEIGHT FEEDERS
VACUUM
DRIVE
TO CASTING
FEED
MIX
DEAERATE
PUMP

FIG. 5

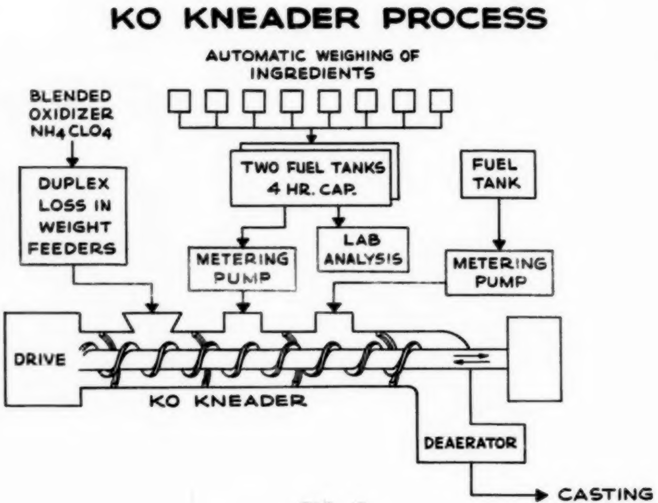

KO KNEADER PROCESS
AUTOMATIC WEIGHING OF INGREDIENTS
BLENDED OXIDIZER NH4CLO4
DUPLEX LOSS IN WEIGHT FEEDERS
TWO FUEL TANKS 4 HR. CAP.
FUEL TANK
LAB ANALYSIS
METERING PUMP
METERING PUMP
DRIVE
KO KNEADER
DEAERATOR
CASTING

FIG. 6

batch on a "go" or "no-go" basis cannot be afforded when high through-puts are required. Quality acceptability should be continuously ascertained and error correction should be an instantaneous function of the process. Without such an approach the propellant mass would not be homogeneous and casting time would be prohibitive unless a very large array of equipment were involved. Economics of production in large units are dependent on small losses due to quality deviation. By employing instantaneous correction of off limit conditions such losses can be minimized. Also low manpower costs are dependent on high production rates from a fully automated plant. Repetitive cleaning and readying of equipment is a contingency which low cost continuous production cannot tolerate.

FUTURE SOLID PROPELLANT PRODUCTION TECHNIQUES

We at Rocketdyne were convinced that an entirely fresh approach was required to meet the needs of the advances in solid rocket technology. In 1958 work was done on a bench scale model of a continuous mixing process and in early 1959 a pilot plant of 500 pounds per hour was developed. This process which is known as QuickMix, has undergone a number of improvements until it appears that a 1,000-pound per hour plant on an 8-foot x 35-foot truck trailer is feasible. Figure 7 and 8 will give you some idea of how compact this plant is.

In the QuickMix process the basic principle is combining perchlorate and a liquid polymer to form a composite propellant (Figure 9). The propellant components are predispersed in high velocity streams of volatile, low density liquid carrier. The streams are brought together in a small volmue mixer (Figure 10) which is the heart of the process. Here instantaneous mixing occurs. Three predispersed streams are used

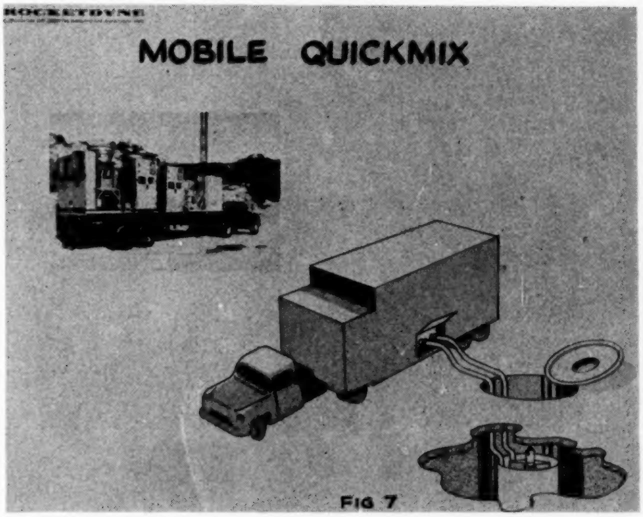


FIG 7

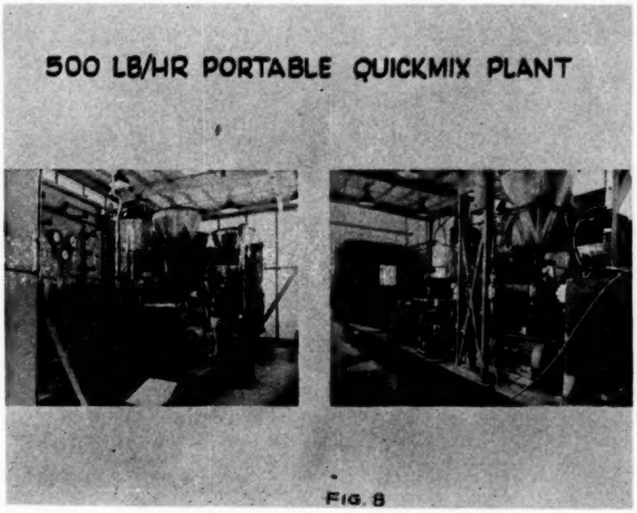
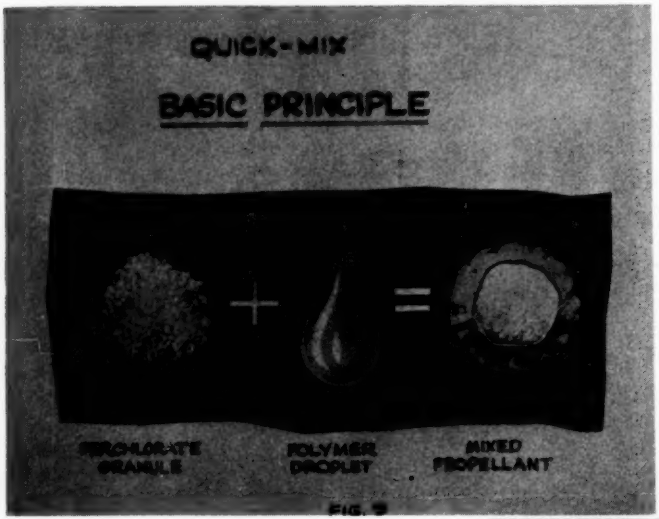


FIG. 8

to handle the solid oxidizer, other solid ingredients, and the liquid polymer binder materials. The low density carrier is gravity-separated from the mixed propellant, with vacuum casting as a final step to remove most of the residual carrier. The QuickMix process offers a number of advantages over conventional processes such as I have described. Figure 11 summarizes these advantages under the heading of cost, safety and uniformity. The first of these, cost, is readily understood when you consider the size and simplicity of the basic QuickMix equipment. Figure 12 shows the basic equipment items required for a plant of 5,000 pounds per hour capacity. For purposes of investment comparison the cost of a screw extruder system is estimated at roughly 20 times that of the QuickMix Plant whereas the conventional batch mixer system (Figure 13) which would require six 200-gallon mixers to equal an output of 5,000 pounds per hour is estimated to cost roughly 100 times as much as a QuickMix Plant.

There are a number of safety advantages (Figure 14) connected with the QuickMix process but perhaps the most impressive is the small amount of mixed propellant in the system at any one instant. The raw materials have little hazard connected to them when suspended in the liquid carrier. It is only when the oxidizer and fuel are brought into close association that the full energy of the propellant becomes available.

One of the requirements for casting large solid propellant engines is uniformity of composition. The uniformity advantages of the QuickMix process are listed briefly in Figure 15. Conventional methods of continuous production of composite propellants involve the direct mixing of dry solid materials with viscous liquid ingredients. To obtain highly uniform compo-

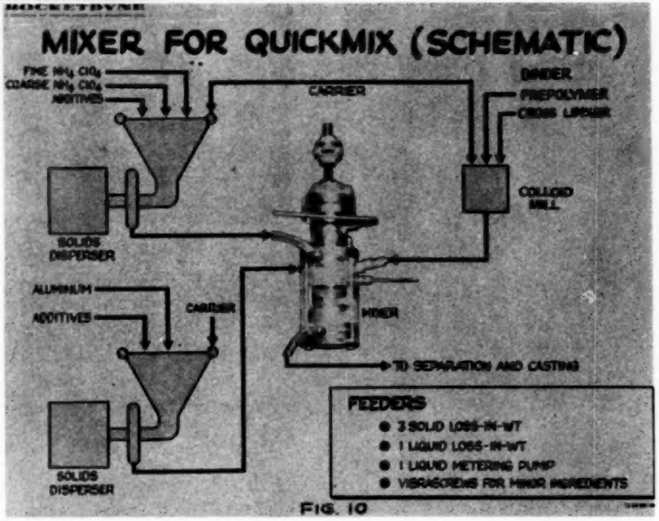


QUICK-MIX

BASIC PRINCIPLE

PERCHLORATE GRANULE
POLYMER DROPLET
MIXED PROPELLANT

FIG. 9



ROCKETDYNE

MIXER FOR QUICKMIX (SCHEMATIC)

FINE NH_4ClO_4
COARSE NH_4ClO_4
ADDITIVES
CARRIER
BINDER
PREPOLYMER
CROSS LINKER
COLLOID MILL
SOLIDS DISPERSER
ALUMINUM
ADDITIVES
CARRIER
MIXER
TO SEPARATION AND CASTING
SOLIDS DISPERSER

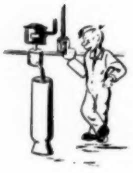
FEEDERS
- 3 SOLID LOSS-IN-WT
- 1 LIQUID LOSS-IN-WT
- 1 LIQUID METERING PUMP
- VIBRASCREWS FOR MINOR INGREDIENTS

FIG. 10

QUICKMIX ADVANTAGES

A. COST
  1. LOWER INITIAL COST
  2. LOWER OPERATING COST

B. SAFETY
  1. SMALL QUANITY IN MIXER
  2. MIXER MECHANICALLY LESS HAZARDOUS
    a. LOW FRICTION
    b. PACKING SEALS CARRIER FLUSHED
    c. NO MECHANICAL HEATING
  3. NO MANUAL CLEANING REQUIRED



C. UNIFORMITY
  1. NO BATCHES
  2. NO MIX TIME VARIABLE
  3. CONTINUOUS METERING
  4. CONTINUOUS MONITORING
  5. REDUCED HUMAN ERRORS

FIG. 11

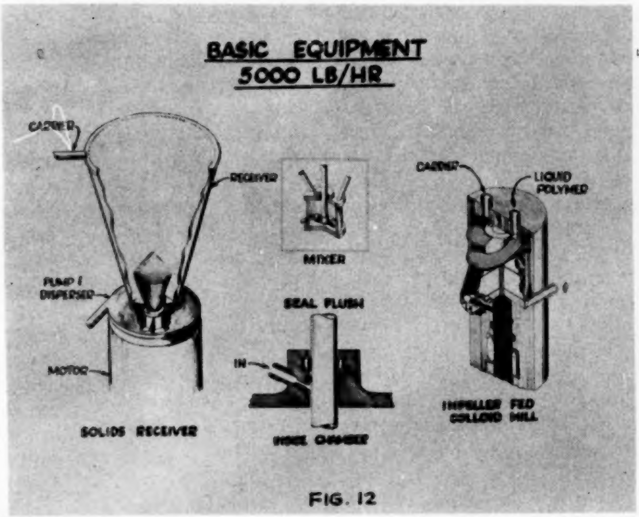

BASIC EQUIPMENT
5000 LB/HR
CARRIER
RECEIVER
PUMP & DISPERSER
MOTOR
SOLIDS RECEIVER
MIXER
SEAL FLUSH
IN
INNER CHAMBER
CARRIER
LIQUID POLYMER
IMPELLER FED COLLOID MILL

FIG. 12

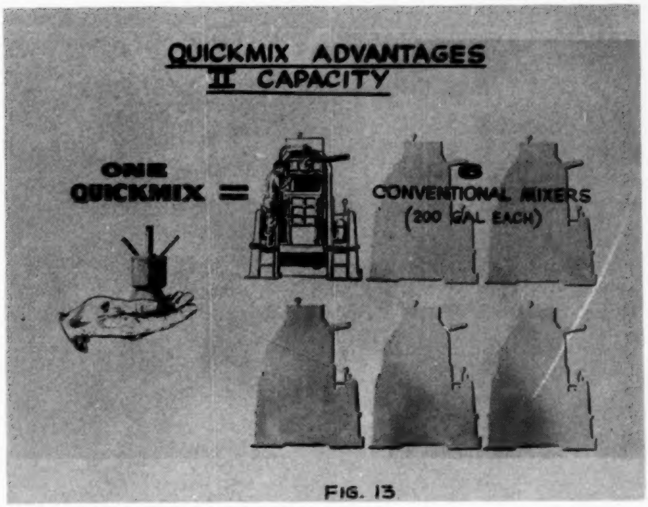

QUICKMIX ADVANTAGES
II CAPACITY
ONE QUICKMIX =
6 CONVENTIONAL MIXERS
(200 GAL EACH)

FIG. 13

QUICKMIX ADVANTAGES
SAFETY

- NO MANUAL LOADING
- NO MANUAL CLEANING
- NO MANUAL OPERATING
- NO LARGE "BOMB"
- NO MIXER HEATING
- NO FRICTION
- NO DUST
- NO FLASHBACK
- NO HOT CURE

FIG. 14

sition, the various ingredients must be delivered from solid feeders to the mixer at very accurate and uniform feed rates. Only a limited amount of back circulation to smooth out feeder fluctuations can be provided in a viscous mixing system unless large size, and thus hazardous mixing system unless large size, and thus hazardous mixing equipment is used. In contrast to such conventional methods, the QuickMix process has the capability of improving propellant ingredients uniformity so that each ingredient in the final product shows so that each ingredient in the final product shows better uniformity than that which was achieved when fed into the system. Since mixing of the predispersed propellant components is extremely rapid and efficient because of the low effective viscosity of the carrier slurry, the main requirement for obtaining high precision and uniformity is that the various streams enter the mixing area with precisely proportioned, nonfluctuating ingredient content.

Generally, automation is viewed as a means of reducing costs in a production process by contributing to longer runs, higher through-puts, and greater speed in shutdowns and start-ups. In solid propellant casting it has an added significance, especially for a portable plant (Figure 16) that must set up in less than stable and predictable conditions for operation. Pre-programming and closed loop feed-back for quality assurance can be adapted in the QuickMix process to reduce waste from discarded off-specification material. Automation of such a process is more than a means of cost reduction. It must be recognized as a technological necessity. Although the QuickMix process is a simple one, it offers great advantages in its adaptability to control of a number of interdependent variables. To realize these advantages the use of computers for analysis and control is essential. At the present time process variables are being studied so that programming the process through electronic data processing equipment can be achieved. Figure 17 portrays the data processing system intended to program and control the process as a fully automated function. Control of this type is capable of instantaneous correction of off-limit conditions and programming a very large number of vari-

QUICK-MIX ADVANTAGES
UNIFORMITY

- NO BATCHES
- NO MIX TIME VARIABLE
- CONTINUOUS METERING
- UNOBSTRUCTED FLOW
- CAPABLE OF CONTINUOUS MONITORING
- REDUCED HUMAN ERRORS

FIG. 15

FIELD LOADING

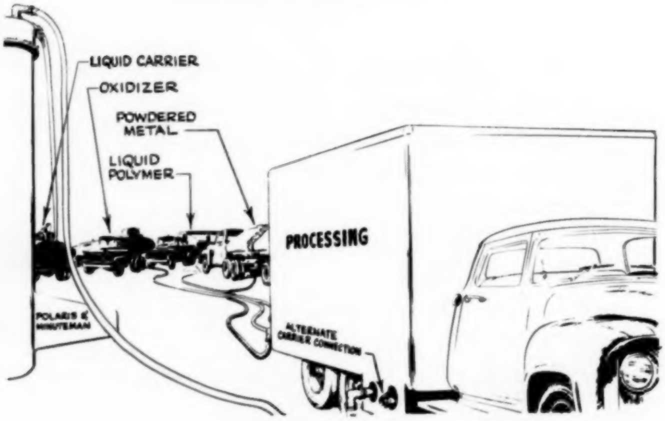
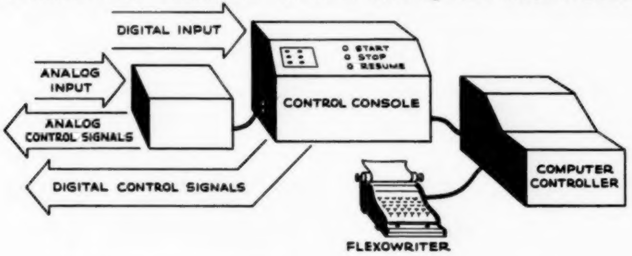


FIG. 16

COMPUTER CONTROL SYSTEM FOR QUICK MIX PLANT


DIGITAL INPUT
ANALOG INPUT
ANALOG CONTROL SIGNALS
DIGITAL CONTROL SIGNALS
START
STOP
RESUME
CONTROL CONSOLE
COMPUTER CONTROLLER
FLEXOWRITER

FUNCTIONS OF AUTO CONTROL SYSTEM

1. CONTROL CRITICAL CONDITIONS
2. DETECT ABNORMAL OPERATIONS
3. DATA LOGGING
4. COMPUTE & SUMMARIZE INFORMATION

FIG. 17

ables. Perhaps the most formidable problems hindering solid rocket flexibility is the limitation in thrust variaton. Computer programming promises such control of composition variables that almost any thrust can be programmed into the case propellant either by variations in propellant layers for end burning configurations or possibly by centrifugal casting of internal burning grains. Data systems offer unusual possibilities for detecting abnormal operations, controlling within critical limits, and developing highly reproductible thrust programmed rocket engines.

CONCLUSION

I have described for you the general problem of meeting the need for solid rocket motors in the coming decade. A solution will certainly touch on such fields of interest as automation, material handling, statistical analysis, production control, cost control, and data processing system design. It is in this broad range of interests that Industrial Engineering will find its challenge in the Sixties.

section 6

SYSTEMATIC LAYOUT PLANNING — A PATTERNED APPROACH TO PLANT LAYOUT PROCEDURE

by **RICHARD MUTHER**
Executive Director

RICHARD MUTHER & ASSOCIATES

Mr. Muther is a graduate of the Massachusetts Institute of Technology, where he received both his B.S. and M.S. degrees. In addition to being a registered professional engineer, he is active in many business and professional societies.

His previous experience includes that of Assistant Professor of Business Management ot Massachusetts Institute of Technology; instructor at Robert College, Istanbul, Turkey and the Navy's training programs, including the Midwest Work Courses on Materials Handling Analysis, Plant Layout and Facilities Planning.

Previously associated with Remington Arms Co., Chrysler Corporaton, Peerless Machinery Co., and the Vendo Co. This latter company is the world's largest manufacturer of automatic merchandising machines.

Has done Management Consulting work in several countries, being previously associated with Institute of Scientific Management, Zurich, Switzerland, and Methods Engineering Council of Pittsburgh, Pa.

Author of the books "Production Line Technique" and "Practical Plant Layout", contributor of two chapters to the "Industrial Engineering Handbook"; author of numerous technical papers and magazine articles on management subjects.

SYSTEMATIC LAYOUT PLANNING—A PATTERNED APPROACH TO PLANT LAYOUT PROCEDURES

by RICHARD MUTHER

Executive Director, Richard Muther & Associates

IF YOU are like most industrial engineers concerned with the planning of plant layouts you should find this topic of particular interest. Most of us have handled our various layout projects in many different ways. And this difference is logical, for there are projects involving complete new facilities on the one hand and minor adjustments in existing layout details on the other.

What is not so logical is that we should follow widely different procedures and that we should grope for techniques of analysis which may not be applicable to the particular project at hand.

Having lived through many of these projects and having felt the lack of clear-cut procedure, I have for some years strived toward finding a logical, realistic, and yet basic approach to the handling of layout projects. This has developed into what has come to be known as Systematic Layout Planning.*

S. L. P. — WHAT IT IS

Systematic Layout Planning is essentially a pattern of steps or procedures. It sets forth the sequence and relationship of each basic step involved in layout planning. The pattern applies both to general overall layouts—block area layouts or space-planning area allocations—and to detailed layout plans. In addition, S. L. P. places each of the patterns into simple focus in the total four-phase route which each layout-planning project should follow.

THE FOUR PHASES OF LAYOUT PLANNING

As each layout project runs its course—from initial stated objective or plan, to installed physical reality—it passes through the four phases of layout planning:

> Phase I is that of *Location.* Here must be decided where the area to be laid out will be. This is not necessarily a new site problem. More often it is one of determining whether the new layout (or relayout) will be in the same place it is now, in present storage area which can be made free for the purpose, in a newly acquired building, or similar type of potentially available area.
>
> Phase II is that of planning the *General Overall Layout.* This establishes the basic flow pattern(s) for the area being laid out and indicates the size, relationship, and configuration of each major activity, department, or area.
>
> Phase III is the preparation of *Detailed Layout Plans,* and includes planning where each piece of machinery and equipment will be placed.
>
> Phase IV is the *Installation.* This involves both planning the installation and physically making the necessary moves.

These phases come in sequence and they should overlap each other.

Phases I and IV are frequently not part of the plant-layout engineer's specific project—even though his project must in every case pass through these first and last phases. Therefore, we shall concentrate our attention on the strictly layout-planning phases: General Overall Layout and Detailed Layout Planning.

BASIC DATA FACTORS FOR LAYOUT PLANNING

Before looking at Phases II and III more closely, we should pause to recognize the basic factors on which we will need facts or information. These are easy to remember when we key them to the "alphabet of the facilities planning engineer"—P Q R S T.

Practically every plant layout starts, or at least relies on, these elements as a basis for its planning.

P—*Product* or material, including variations and characteristics.
Q—*Quantity* or volume of each variety or item.
R—*Routing* or process, which establishes the operations and their sequence.
S—*Services* or supporting activities which back-up the producing operations.
T—*Time* as it relates to P Q R S and to the scheduling of the layout project itself.

With investigation of these elements—particularly as to the product mix and the P-Q inter-relation—we will have the essential data needed to begin our analyses.

THE PATTERN FOR PHASE II—GENERAL OVERALL LAYOUT

The analytical part of planning the general overall layout begins with the study of the *Product* and *Quantity* and their relationship. (See Exhibit 1) Next comes an analysis of the *Flow of Materials.* But in addition to the producing areas, the many supporting-service areas must be integrated and planned. As a result, developing or charting the service *Activity Relationship* is frequently of equal importance.

These two investigations then are combined into a *Flow and-or Activity Relationship Diagram.* Here the various activities, departments, or areas are geographically oriented to each other, although without regard to the actual space each requires.

Next comes the *Space Requirements.* These are developed from analysis of the *Process Machinery and Equipment* necessary and from the *Service Facilities* involved. These area requirements must, however, be balanced against the *Space Available.*

Then the area allowed for each activity will be hung on the activity relationship diagram to form a *Space Relationship Diagram.*

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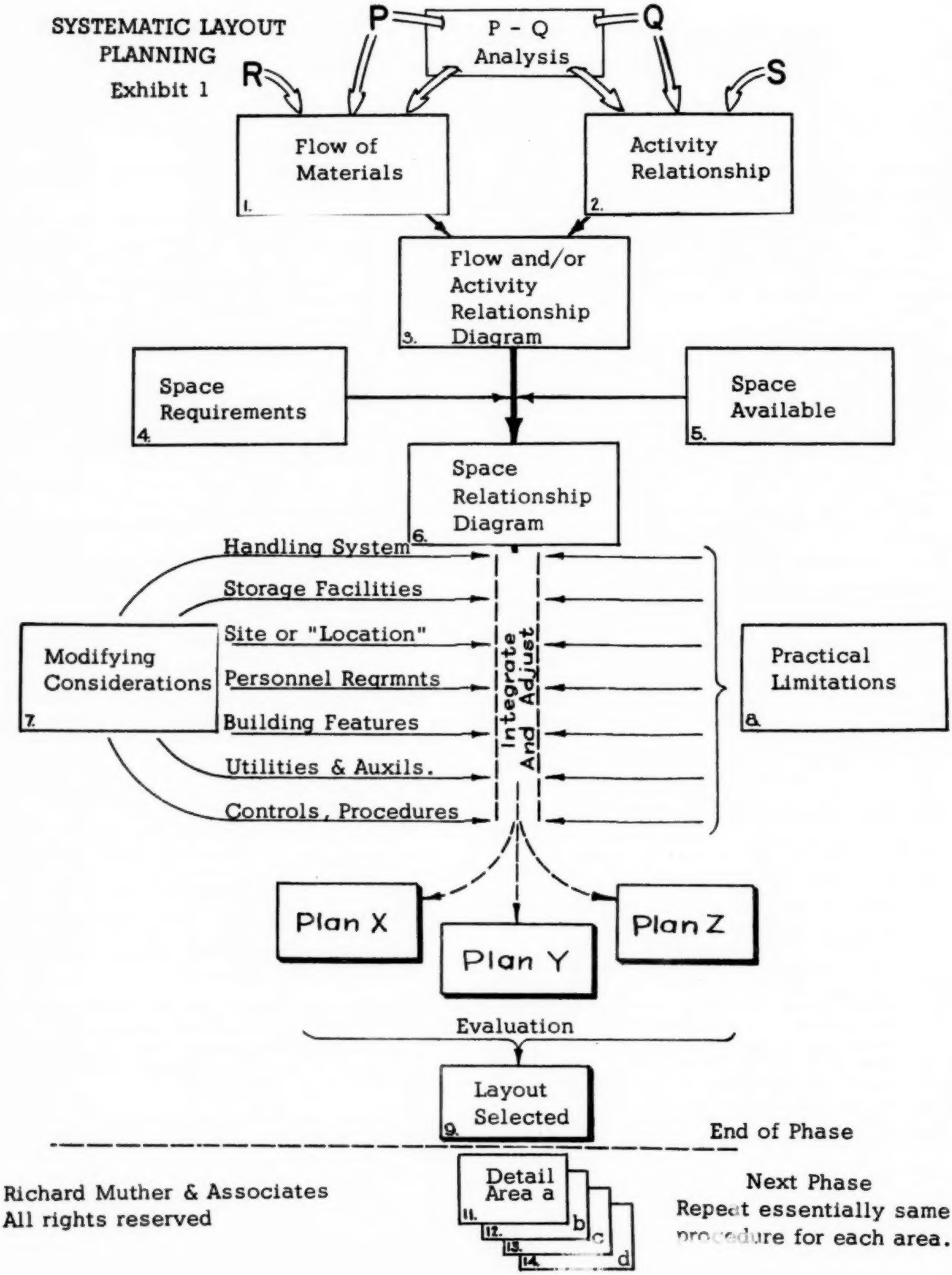
*A book bearing this title is to be published later this year, copyright Richard Muther & Associates.

SYSTEMATIC LAYOUT PLANNING
Exhibit 1


P
P - Q Analysis
Q
R
S
Flow of Materials
1.
Activity Relationship
2.
Flow and/or Activity Relationship Diagram
3.
Space Requirements
4.
Space Available
5.
Space Relationship Diagram
6.
Handling System
Storage Facilities
Site or "Location"
Personnel Reqrmnts
Building Features
Utilities & Auxils.
Controls, Procedures
Integrate And Adjust
Modifying Considerations
7.
Practical Limitations
8.
Plan X
Plan Y
Plan Z
Evaluation
Layout Selected
9.
End of Phase
Detail Area a
11.
b
12.
c
13.
d
14.
Next Phase
Repeat essentially same procedure for each area.

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The space relationship diagram is essentially a layout. But it is not an effective layout—in all likelihood—until it is adjusted and manipulated to integrate with its space the *Modifying Considerations* which can affect it. These include such basic considerations as the handling system, the storage facilities, the building features, the production control system, operating practices, safety considerations, and the like. And as each potentially good idea concerning these features is thought up, it must face the challenge of practicality—represented by the *Practical Limitations* at the right.

As the integrating and adjusting of the various modifying considerations and their limitations are worked out, one idea after another is probed and examined. The ideas that have practical value are retained and those that do not stand the test are discarded. Finally, after abandoning those plans which do not seem to stand up, we end up with two, three, four, or five alternative layout proposals. Each of these will work; each of these has value. The problem lies in deciding which of these plans should be selected.

These alternative plans may be termed *Plan X, Plan Y, Plan Z.* At this point a cost analysis of some kind should be made. But frequently these turn out to be a standoff. In any event, some evaluation of intangible factors should also be made. This may be represented by what might generally be called an evaluation of alternative layouts or an evaluation of costs and intangibles. As a result of this *Evaluation,* a choice is made in favor of one alternative or the other—although in frequent cases a modification of two or more layouts may actually result from the evaluation process itself.

By evaluation, one of the alternative layouts is chosen. This layout becomes the *Layout Selected.* With the selection of this general overall layout, Phase II is completed.

TIE-IN OF PHASE III—DETAILED LAYOUT PLAN

The next phase—Phase III—is that of making the detailed layout. This involves the detailed planning of each piece of machinery and equipment, aisle, and storage area, for each of the activities, departments, or areas which have been blocked out generally in the general overall plan.

By reference to Exhibit 2 we see that Phase III overlaps Phase II. This means that before actually finalizing the general overall layout certain details will have had to be looked into. For example, the actual orientation of a conveyor system may have to be analyzed in order to arrive at a satisfactory solution to the general overall layout. This means that detailed study of this conveyor would be necessary before a satisfactory general overall layout is worked out. This is the kind of overlapping investigation that takes the layout planning engineer into detailed layout planning in certain areas before his Phase II is selected. We recognized this overlapping earlier and it should not be lost sight of merely because we have discussed here the general overall layout as a distinct pattern—separate from Phase III—detailed layout plan.

Note also that a detailed layout plan must be made for *each* of the departmental areas which are involved. This means that some adjustment will be made between these detailed areas, and that some readjustment of the general overall layout selected may also be called for. That is, even though a basic general overall layout has been agreed to, it can be adjusted and changed within limits, as the details are worked out.

As for planning the detailed layouts, the same essential pattern used in Phase II is repeated. However, now the flow-of-materials becomes the movement of materials within the department in question. The activity relations now become relations of the activities within the department in question. Similarly, the space requirements now become the space required for each specific piece of machinery and equipment, and the space-relationship diagram now becomes a rough arrangement of templates or other replicas of machinery and equipment, men, and materials or products.

Again we end up with several alternatives. This leads to an evaluation to select the most satisfactory.

This same pattern is repeated for each departmental area which is to be layed out in detail.

S. L. P.—A UNIVERSAL PATTERN

This explanation shows a universally applicable pattern to any layout project. If you are planning an office area or a laboratory or some other service activity, then the content of the P Q R S data, as shown at the top of Exhibit 1, will be modified. Similarly, the flow-of-materials analysis will become less important and the activity relationship study will become more important. Therefore, once the pattern is established it becomes a matter of adjusting the importance of each "box" rather than by changing the sequence or arrangement of boxes.

S. L. P.—AN EXAMPLE

By way of further explanation, let us trace through an actual example. This example pertains to a company manufacturing high pressure valves used in the oil and chemical industry. The example is taken from an actual layout-planning project, although the product information and the forecast sales figures have been altered so as not to reveal the company in question.

Exhibit 3 shows this example in detail. Here you will note, based on the products to be produced and the sales which were forecast, that analyses were made of the product-quantity relationships. Then by picking up the routing as expressed in the operations sheet, a flow of materials was prepared. Likewise, a list of supporting services was established.

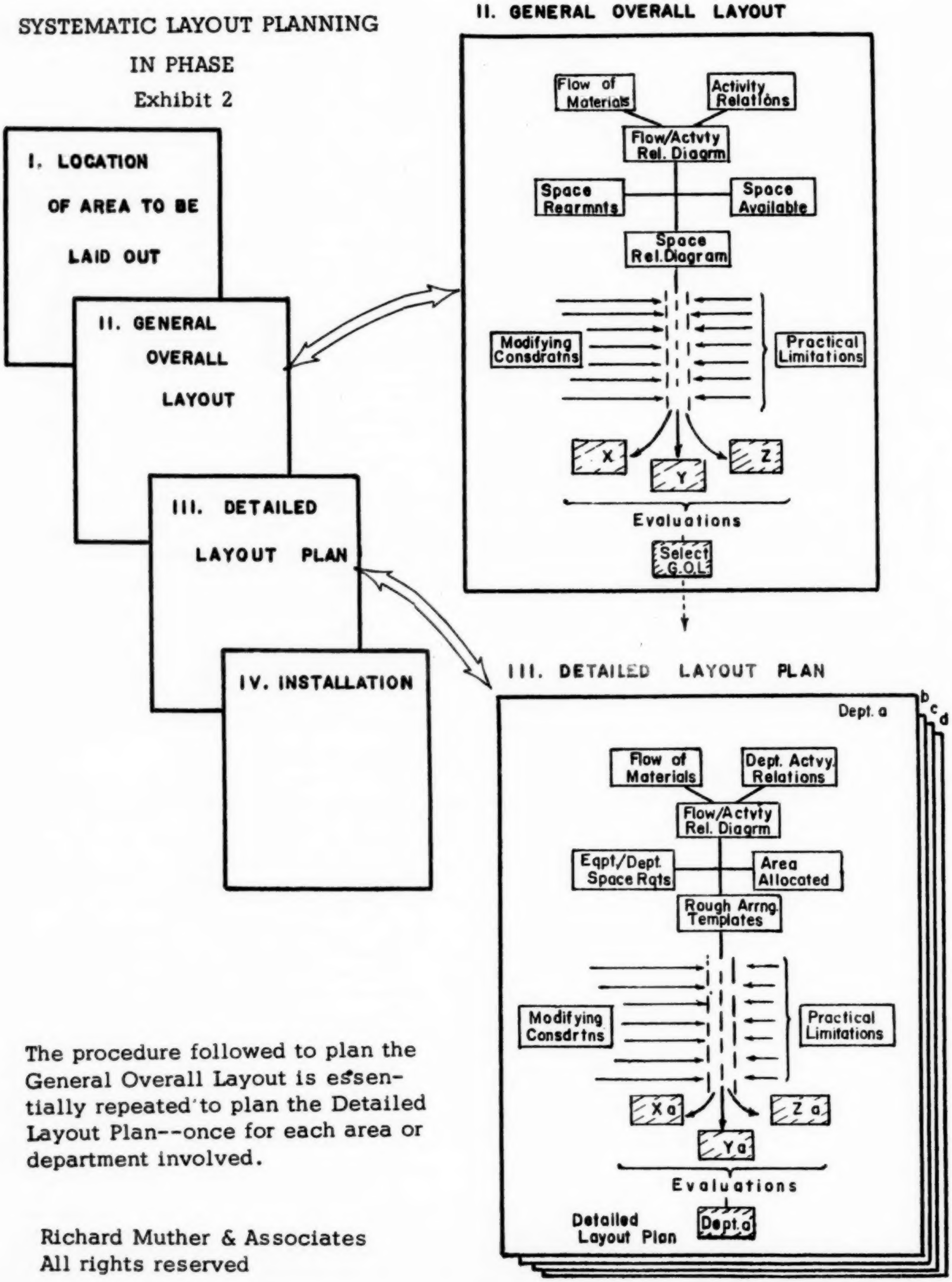
The flow of materials and the supporting service relationship were combined into an activity relationship chart. Here, the producing departments as well as the supporting departments are included.

From this, an activity relationship diagram was prepared. Then the space requirements for the process machinery and equipment and for the service facilities were established. These were added to the activity relationship chart and the space was arranged into actual patterns for the respective departments in the desired

SYSTEMATIC LAYOUT PLANNING

IN PHASE

Exhibit 2


I. LOCATION OF AREA TO BE LAID OUT
II. GENERAL OVERALL LAYOUT
III. DETAILED LAYOUT PLAN
IV. INSTALLATION
II. GENERAL OVERALL LAYOUT
Flow of Materials
Activity Relations
Flow/Actvty Rel. Diagrm
Space Reqrmnts
Space Available
Space Rel. Diagram
Modifying Consdratns
Practical Limitations
X
Y
Z
Evaluations
Select G.O.L.
III. DETAILED LAYOUT PLAN
Dept. a
b
c
d
Flow of Materials
Dept. Actvy. Relations
Flow/Actvty Rel. Diagrm
Eqpt/Dept. Space Rqts
Area Allocated
Rough Arrng. Templates
Modifying Consdrtns
Practical Limitations
Xa
Ya
Za
Evaluations
Detailed Layout Plan
Dept. a

The procedure followed to plan the General Overall Layout is essentially repeated to plan the Detailed Layout Plan--once for each area or department involved.

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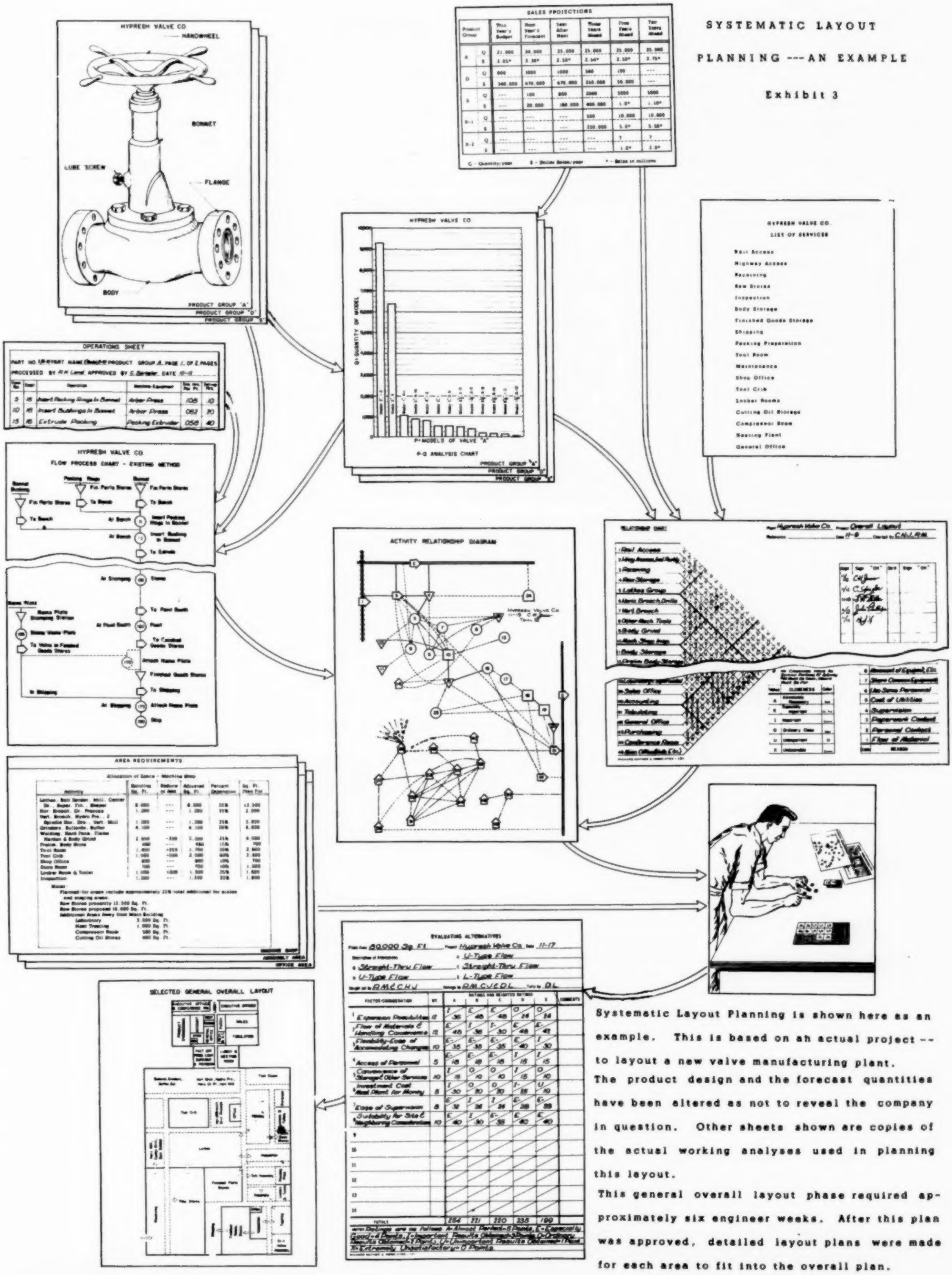
SYSTEMATIC LAYOUT PLANNING --- AN EXAMPLE

Exhibit 3


HYPRESH VALVE CO
HANDWHEEL
BONNET
LUBE SCREW
FLANGE
BODY
PRODUCT GROUP "A"
PRODUCT GROUP "B"
PRODUCT GROUP "C"
SALES PROJECTIONS
HYPRESH VALVE CO
Q= QUANTITY OF MODEL
P= MODELS OF VALVE "A"
P-Q ANALYSIS CHART
OPERATIONS SHEET
HYPRESH VALVE CO.
FLOW PROCESS CHART - EXISTING METHOD
ACTIVITY RELATIONSHIP DIAGRAM
RELATIONSHIP CHART
Hypresh Valve Co.
Overall Layout
AREA REQUIREMENTS
Allocation of Space - Machine Shop
MACHINE SHOP
ASSEMBLY AREA
OFFICE AREA
EVALUATING ALTERNATIVES
80,000 Sq. Ft.
Hypresh Valve Co.
U-Type Flow
Straight-Thru Flow
L-Type Flow
SELECTED GENERAL OVERALL LAYOUT

HYPRESH VALVE CO.

LIST OF SERVICES

Rail Access
Highway Access
Receiving
Raw Stores
Inspection
Body Storage
Finished Goods Storage
Shipping
Packing Preparation
Tool Room
Maintenance
Shop Office
Tool Crib
Locker Rooms
Cutting Oil Storage
Compressor Room
Heating Plant
General Office

Systematic Layout Planning is shown here as an example. This is based on an actual project -- to layout a new valve manufacturing plant.

The product design and the forecast quantities have been altered as not to reveal the company in question. Other sheets shown are copies of the actual working analyses used in planning this layout.

This general overall layout phase required approximately six engineer weeks. After this plan was approved, detailed layout plans were made for each area to fit into the overall plan.

relation to each other.

During this process the many modifying considerations were incorporated into the planning and the practical limitations were weighed. By adjustment and readjustment, the space was integrated to the most desired arrangement and configurations.

Actually, five alternative arrangements seemed practical and these were diagrammed out so that an evaluation could be made of each one. The evaluation of the costs and the intangibles resulted in the selected general overall layout.

This exhibit shows the sequence which was actually followed in planning a new plant of approximately 90,000 square feet. This Phase II required approximately six engineer weeks of study.

After this general overall layout was agreed to, certain modifications were made to make sure the building features were satisfactory from an architectural standpoint. Then, with these specific building details pinned down, each department was layed out in detail.

CONCLUSION

This presentation describes the pattern known as Systematic Layout Planning. It is both a pattern of procedures and an approach to the solving of layout problems.

This pattern puts into proper relation the many procedures and techniques which are used in layout-planning work, and it should serve as a guide in the scheduling and programming of plant-layout work. It is a surprisingly simple device, yet one we have found can save many hours and avoid many delays and misunderstandings.

Here then, is a universal pattern which has been proved by use and which, when followed, can bring sequence and clarity to what on each project seems a "different" problem. True, every layout project is different—for no two layouts are exactly alike. But there is an approach and pattern for the planning of layout work—Systematic Layout Planning.

section 7

HOW NOT TO MAKE EQUIPMENT REPLACEMENT DECISIONS

by **RALPH O. SWALM**
Professor, Department of Industrial Eng.
L. C. SMITH COLLEGE OF ENGINEERING

Ralph Swalm is Professor of Industrial Engineering at Syracuse University. He has been active in AIIE almost since its inception, having served on the Education and Curriculum Committees, as National Director of Programs, and currently as chairman of the Engineering Economy Research Committee and as director of the Syracuse Chapter.

He spent eleven years with the General Electric Company, having set up and administered the job evaluation and incentive system for the Coshocton, Ohio plant. He joined the staff of Syracuse University in 1948, and in 1957, while on leave of absence, spent seven months with Asbjorn Habberstad A/S, Morway's leading consulting firm. He was the director of a two year research study, sponsored by Yale & Towne, on the economics of lift truck replacement.

Professor Swalm is on the staff of the Material Handling Training Conference at Lake Placid, New York and the Syracuse University Executive Controls Program, and has been appointed visiting Professor of Industrial Engineering at Stamford University this summer.

HOW NOT TO MAKE REPLACEMENT DECISIONS

by Ralph O. Swalm

Professor of Industrial Engineering, Syracuse University

INTRODUCTION

WHEN is it economical to replace a machine with a similar, but newer machine? That is a simple question, which sounds as though it should have a simple answer. Unfortunately, in industry today, it receives not one but a whole host of answers—and many of them are mutually incompatible.

Let me illustrate this through the use of an example. I shall choose a simplified example, for as Deming has said, "Simple problems are always best for illustration; if we can understand the simple problems there is some hope that we can understand the more complicated ones."

Of course, there are dangers in over simplification. A truly realistic problem is seldom simple. A method of approach that appears to be correct in a simple case may lead to false answers in a complex problem. On the other hand, if a method of approach can be shown to yield a false solution to a simple problem, there is great reason to question its ability to yield a correct solution in the complex, realistic case.

Since it is my prime purpose here today to demonstrate that a number of widely used approaches yield misleading results, I shall be quite content to employ a simple example—and to hope that some of you become sufficiently intrigued with this subject to pursue it further.

THE PROBLEM

Consider with me, then, if you will, the following problem:

A year ago, in the land of Monaco, where they have not only a beautiful queen but also no income taxes, a grocer took a seven year lease on a building that, by imperial decree, had to be torn down at the end of that period. He used the building as a warehouse, and one of his first moves was to install a conveyor he had seen advertised in an American publication, at a cost of $21,000. He depreciated this on a straight line basis.

Last week a consultant, who described himself as an industrial engineer, visited the warehouse. After touring it, he concluded that the grocer had the right idea but the wrong conveyor. He recommended a new Swedish model, costing $18,000, which could definitely eliminate the need for one man and thus yield an annual savings of $5,000. The grocer is convinced that the savings can be obtained, and the man used elsewhere. The salesman for the new conveyor offers $3,000 for the old one, and no one else can be found who will pay more.

If all other operating costs remain unchanged, and if the net salvage value of either conveyor will be zero when the building is torn down, would the grocer be well advised to take the consultant's advice?

Despite the fact that it took about 700 words to state it, I think you will agree that this is a simple problem compared, say, to the one of whether or not you should listen to that new car salesman and replace your car this Spring.

Let's boil our problem down, leaving only the essentials. A conveyor was bought a year ago for $21,000. It was depreciated on a 7-year, straight line basis. A new conveyor, costing $18,000 and saving $5,000 per year is now proposed. A $3,000 trade-in allowance is offered for the old conveyor; either conveyor will have no net value when the building is torn down in six more years. Should the proposal be accepted?

Now, of course, I don't know how your company would make such a decision—but I do know how many of your industrial colleagues would do so. And I'd like to outline with you some of the approaches I've seen—and to examine their implications.

Unfortunately, there seem to be almost as many approaches as there are companies. Perhaps these can be divided into two broad categories—first, those that do not, implicitly, at least, make use of the concept of an interest rate, and second, those that do.

THE PAY-OFF APPROACH

In the first category is the approach most commonly found, that of "we'll buy it if it will pay for itself in X years", with X generally being a low number, and most commonly not greater than 3.

Analyst A, might, therefore, reason as follows:

"I'll buy it if it will pay for itself in 3 years. Let's see—the new conveyor will save $5,000 per year times 3 years, or $15,000 in three years. But its cost is $18,000. Therefore, we won't buy it."

"Not so", says Analyst B. "Your $15,000 figure is correct, but the cost is not $18,000 but $15,000, since you get a trade-in allowance of $3,000. Thus it *just* pays off in 3 years—and might, therefore, be attractive!"

"You're both crazy", says Analyst C. "Of course, the $15,000 3-year savings you agree on is correct—but you have both forgotten the loss on book value you sustain in selling. Remember, the old conveyor cost $21,000 one year ago—has a value of $17,000 now. You propose to sell it for $3,000 a clear loss of $14,000. Thus, your new conveyor costs you not $15,000, not $18,000, but $18,000 cost plus $14,000 loss on the existing conveyor, or $32,000. So A was right in saying Don't Buy—but he was right for the wrong reason. Had the savings been $7,000 per year, he'd have said "buy"—but the three year payout would be only $21,000, on an investment of $32,000! In this case you shouldn't buy—but B's approach would cause you to."

"Wait a minute!", says Analyst D. "I agree with A that your capital costs are actually $18,000—but you are obviously going to keep the conveyor, if you buy it, for 6 more years. So we should ask whether or not it pays a sufficient amount above $18,000 in 6 years. Since in this period it will save $5,000 x 6 or $30,000 on the $18,000 investment, it seems to me it should be purchased!"

"Right answer—wrong reason" says E. "I agree with B that your costs are $15,000—so you save the difference between $30,000 on $15,000, or $15,000."

"Not so," says F., "as C pointed out, your costs are the $18,000 you spend plus the $14,000 loss on book value—so that even though you save $30,000 in 6 years, that is not enough to pay for the $32,000 cost!"

Who is correct—A, B, C, D, E, or F?

"None of them are," say other analysts. "They all use too simple a decision rule. What they should do is calculate the return on the investment to see if it is sufficient."

THE RATE OF RETURN APPROACH

"Yes" says G, "the return is $5,000 on a cash investment of $18,000. Dividing $5,000 by $18,000 gives a return of about 28%. That's "quite attractive" (of course G and H calculate the return as $5,000 on an investment of $15,000 and $32,000 respectively—getting answers of 33 and one-third per cent and 15.6%). They used the same arguments for the amount invested as did B and C (or E and F). But J agrees with none of these.

"I'm now confused as to which of you are right about the amount of the investment," he says, "but I'm sure you all forgot to subtract the depreciation on the new equipment from your $5,000 annual saving. If the cost is taken as $18,000, the numerator in your calculation should be reduced by a depreciation of $\frac{\$18{,}000}{6}$ or by $3,000. Your income after depreciation is then $2,000; dividing this by the capital cost of $18,000 gives a return of about 11%. Analyst K, using $15,000 as the cost, calculates the interest as.

$$\frac{\$5{,}000 - \frac{\$15{,}000}{6}}{\$15{,}000} \quad \text{or} \quad \frac{\$5{,}000 - \$2{,}500}{\$1{,}500} \quad \text{or} \quad 16\text{-}2/3\%$$

and L, using $32,000 as his cost, gets a negative return. Then, of course, there is M, who uses $15,000 in the denominator but $18,000-6 for depreciation, yielding 13.3%, and N who uses the same numerator, but $32,000 as the denominator, yielding an interest rate of about 6%.

By now, you are probably not surprised to find that Analyst O feels that none of these is correct. He points out that although he agrees that the original cost of the new equipment is $18,000, that this amount will be recovered over the next 6 years—and that therefore the average investment is half of that amount, or $9,000. He therefore calculates the return as $5,000 annual income divided by $9,000 average investment or about 56%. And then, of course, there follow P and Q who use $5,000 as numerator and half of $15,000 and $32,000 respectively for indicated interest rates of about 67% and 31% respectively, and R, S, T, U, and V who calculate numerators, allowing for depreciation, exactly as J, K, L, M, and N but halve the denominators to allow for the average investment—yielding results of about 22%, 33% negative, 27% and 12.5% respectively.

We have by no means exhausted all the permutations and combinations possible in computing a rate of return, but I fear that to continue would be exhausting to the audience and add little to the point already made—that there are many approaches all described by the same term—"The Rate of Return Method", and that they give mutually exclusive answers. Although the methods supported by Analysts G through V are simplifications of the actual methods used (because of the simplicity of the problem) I have seen with my own eyes, reports from companies that based their decisions on calculations similar to almost every one of these approaches.

OTHER APPROACHES

Of course, there are other methods than these in use. Some are almost unbelievable. If you'd like, I'd be glad to describe some of these during the question period. Others seem based on fairly sound analysis. Typical of these is the MAPI Method—or, more exactly, the revised MAPI Method. It is impossible to begin to explain this method in the time we have at our disposal and besides, it is based on several assumptions that obviously are false in this case, so it should not be used. Despite this, a number of companies have standard operating procedures that require its use indiscriminately, and these companies would find, for projection rating 1, that it showed an urgency rating of only 4%, which would make the installation of the new conveyor very dubious.

Another approach is the Present Worth—or Discounted Cash Flow—or Profit-ability Index—or Venture Worth Method. They are all essentially the same thing dressed up with different names. In each, in effect, the interest rate is found which equates the cash outflows to the cash inflows, taking into account the time value of money. Each would, in our problem, find the interest rate that equates a present net outgo of $15,000 to a future inflow of $5,000 a year at the end of each of the next 6 years. If annual compounding is assumed, the result is about 24.3%.

Incidentally, this approach is much more easily justified in this particular problem than in a more typical replacement problem in which the lives of the existing and proposed assets are different.

If we wish to add the complexity of a minimum return on invested capital, we could approximate the average annual costs of each alternative by adding the average interest to the totals already obtained. Or, we can get an exact answer by using the product of the invested capital and the appropriate capital recovery factor, as found in any interest table, as the average annual cost of capital. For 24.3% this factor is 0.333, so the *average* annual cost of capital for the old conveyor is $3,000 x 0.333, or $1,000. Adding "extra" operating costs of $5,000 to this yields a total average annual cost of $6,000.

The capital cost for the new conveyor is $18,000 x 0.333, or $6,000, and this is the total (comparative) average annual cost. We, therefore, conclude that if a 24.3% return is required, it is a matter of indifference whether the grocer replaces or not. Stating this another way, it means that if he does replace, he will earn a 24.3% return on his investment.

I suppose we should call these last four methods (MAPI, Present Worth, average annual cost without interest and average annual cost with interest) those of Analysts X, Y, Z_1, and Z_2 and then breathe a sigh of relief because we have only 26 letters in our English alphabet.

ANALYSIS

In our remaining time, I should like to try to bring some order out of the chaos I have now created. Which, if any, of these 26 methods gives a correct answer—for the correct reason. It is important that we add the stipulation that it be for a correct reason, for after all, our problem has, in one sense, only three possible answers—yes, no, and maybe—and any method could select the right one of these by chance in a particular problem.

Let us first look at the methods in which an interest rate does not play a part—or which assume zero interest. These are methods A, B, C, D, E, and F (all variants of the pay-out method) and method Z_1 (the annual cost—no interest method). In essence, all of these ask whether or not the savings exceed the investment by a sufficient amount to make the investment attractive. What are the actual incomes and outgoes—and by how much do they differ? Can we not answer the question, in this rather special case, by simply adding up all expenses, for each alternative, from the beginning to the end of the project.

If the consultants advice is ignored, the expenses will be:

At start	$21,000
During 1st year	5,000
At time of decision	0
During 2nd year	5,000
During 3rd year	5,000
During 4th year	5,000
During 5th year	5,000
During 6th year	5,000
During 7th year	5,000
Total	$56,000

If the consultant's advice is taken, the expenses will be:

At start	$21,000
During 1st year	5,000
At time of decision	15,000
($18,000 spent less $3,000 received)	
During 2nd year	0
During 3rd year	0
During 4th year	0
During 5th year	0
During 6th year	0
During 7th year	0
Total	$43,000

The difference between these figures shows a net savings of $15,000 or $2,500 per year in the remaining 6 years! If you have been taking careful notes, you'll find that analysts E and Z_1 got this result, but that A, B, C, D and F got different answers.

E was the one who compared the savings over 6 years to a cost of $15,000. Z_1 used average annual costs at zero interest.

But lots of business men—including, I am sure, many among you—will insist that the *real* cost is not $15,000 but $18,000 plus the loss on the BOOK VALUE OF THE OLD CONVEYOR, or $32,000. Why is this wrong?

Well, let us look at our totals. We'll put them down side by side for easier comparison:

	COSTS IF	
Time of Expense	Old Conveyor is kept	New Conveyor is bought
At start	$21,000	$21,000
1st year	5,000	5,000
Time of decision	0	15,000
2nd year	5,000	0
3rd year	5,000	0
4th year	5,000	0
5th year	5,000	0
6th year	5,000	0
7th year	5,000	0
Total	$56,000	$41,000

Now suppose the original conveyor had been in the building when it was leased—and had *no* cost. How would these figures change? The total for keeping would be reduced by $21,000—but so would the total for buying—and the difference would remain at $15,000 in favor of buying. So we see that here, with *no* loss on book value, the answer is the same as with a $14,000 loss. In fact, no matter *what* original cost is put in, the savings remain the same. The original cost is irrelevant in our problem, and since the book value is a function of this cost, the book value *must* be irrelevant, and any method that does not consider it so wrong. The economists have long known this—but many business men who loudly proclaim that the public knows too little economics have yet to learn this lesson in basic economics.

Let us draw this part of the discussion, which deals with methods used in industry, to a close by adding the average annual cost approach. To make this comparable to the results obtained by Analysts A, B, and C we shall first use it assuming zero interest rate; after which we shall use a 24.3% rate.

In either case, we shall simply add the average annual cost of capital to the average annual operating cost for each alternative to get the total average annual cost for that alternative. To simplify matters, we shall charge the existing equipment with an *extra* $5,000 operating cost and the new with no *extra* cost.

The capital cost of the existing asset is $3,000—the amount you forego by keeping it. Pro-rated over 6 years, the *average* annual cost of capital is $500 per year. Adding $5,000 extra operating cost yields a total average annual cost of $5,500 for keeping the old conveyor in service. It will cost $18,000 or $3,000 per year capital cost for the new conveyor—and since it has no "extra" operating costs, this is its average annual cost. Therefore, by accepting the engineer's advice the grocer will save the difference between the total average annual costs of the new and old conveyors. In dollars, this amounts to $5,300 minus $3,000 or $2,500 per year for the next 6 years.

But now that we know that $15,000 can be saved in the next 6 years by buying the conveyor, should it be bought? Not necessarily—for we may have better uses for the funds required. One way to examine this is to ask what rate of return we make on our investment. But here again we get into difficulty, for Analysts G through W and Y all purported to calculate this, and Z2 did essentially the same thing by assuming a rate and then examining the resulting comparison. And these rates ranged from negative to 56% through many intermediate steps.

Let us, for the moment, ignore *all* of these, and look again at our calculation for zero interest rate. Here we were able to add sums of money at differing times because we assumed zero interest. To make a legitimate addition with a positive interest rate, we can *discount* each of these sums to a common time, then add them. We can do this with differing interest rates until we find, by trial and error, that rate which makes the two alternatives equally attractive. Even simpler, we can take the algebraic difference between the alternatives and discount these to a common time at various interest rates, until we find that rate which makes the sum zero. But this is the discounted cash flow system Analyst Y used—and his result was 24.3%. Analyst Z, in setting up an annual cost comparison also showed that, at 24.3% the alternatives were equal. He could just as easily have set the totals equal and solved for the interest rate that made them so—and gotten 24.3%. This, then, is *the* correct rate of return, in the tax-free land of Monaco. All the rest—and that includes Analysts G through W—got the *wrong answer*. Some of these can be shown to offer fairly good approximations to the correct answer under certain circumstances, and others under others. But none, in this case, give the right answer. Furthermore, those that come closest do so by chance, and would give *very* poor approximations in other cases.

The fact that several of these are quite widely used doesn't alter the fact that they give an incorrect answer.

I'd like to suggest that many companies would consider a return of about 25%—even though this is a before tax return—quite attractive—and to point out that they would deny themselves this return if they had used the common 3 year pay-off requirement.

CONCLUSION

In closing, let me briefly recapitulate what I've tried to do here today. First, I've tried to demonstrate that there are a whole host of seemingly plausible approaches to a replacement problem, and to suggest that just about all of these are in use today. Second, I've tried to show that if some of these are right, others must be wrong, for they give differing answers. Third, I've tried to show which, in a specific problem, give demonstrably correct results. Fourth, I've attempted, through this maze of calculations, to show that *any* method which adds the loss on book value to the cost of the new equipment leads to a wrong answer, because it violates the fundamental economic precept that "past events are irrelevant except as they aid in the prediction of the future". And finally, I hope to have whetted a few of your appetites—titillated a few of your curiosities—so that you'll leave this convention determined to explore further the very fascinating subject of machine replacement. If I have done this, my coming here has surely been worth while.

section 8

WORK SAMPLING

by K. LIFSON

LIFSON - WILSON - FERGUSON, INC.

Dr. K. A. Lifson has been in management consulting work since 1946, and has been a member of the Dallas and Houston firm of Lifson, Wilson and Ferguson, Inc., for over six years. He has an engineering degree, a Master's in Business Administration from the University of Minnesota, and a Ph.D. in Industrial Psychology from Purdue University. His work has included experience in diverse industries, including aircraft, garment, electronics and meat packing.

WORK SAMPLING: USES AND ABUSES

DR. K. A. LIFSON

President, Lifson, Wilson & Ferguson, Inc.

DESCRIPTION

WORK sampling is a technique for determining the proportions of time spent in various activity categories. The technique involves the making of random observations of people or equipment and noting what the subject is doing at the instant of observation. If the subjects are handling material in 30% of the instant observations, one assumes that 30% of the time of the subjects is spent in material handling activities. Usual statistical measures of reliability apply to the results, with the usual restricting assumptions of randomness of observations and patterns of variations. Large numbers of observations are usually required, but the technique is relatively inexpensive. Observers can be trained in less than a day, and frequently supervisors or foremen can do the observing.

APPLICATIONS

In many situations some estimate must be made of the division of time into various categories. When time standards do not exist for all of the work categories, the work sampling technique may be appropriately used. We believe there is an important distinction between using work sampling to determine and describe a time distribution that *does* exist, and attempting to find by work sampling the conditions that ***should*** exist. The description of existing conditions, as to determine allowances, prepare job descriptions, or seek areas for improvement, we believe a proper use of work sampling. The attempt to set standards or goals by work sampling, we believe, results in the goal of "looking busy" and is usually an abuse of industrial engineering technology.

Work sampling can be of help in determining manpower and equipment needs, but only in conjunction with some measure of the occurrence of the needs.

SEEKING AREAS OF IMPROVEMENT

A frequent good use of work sampling is the determination of potential cost savings in unmeasured or highly variable work categories. Activity categories are defined so that the work sampling results are in terms of time spent in material handling, planning, paperwork, getting tools, receiving supervision, rework, or other such activities as one believes are susceptible to reduction through further investigation. We have applied work sampling, for example to the work content of sewing machine operators making work clothes. It was determined that 24% of the time was spent in machine operation, 16% in prepositioning or repositioning the garment on the work table, 40% handling pieces to or from the bundle, 3% handling material while not seated, 4% idle, 12% performing non-sewing work such as clipping, measuring, and trimming, and 1% miscellaneous. Thus it seemed likely that 24% of the time was subject to improvement by new and faster machines, 16 to 40% by operator training and workplace layout improvement, 40% by materials handling devices and better breakdown of operations, and 3% by hiring a "bundle runner". Our concentration is on lengthening the work elements, providing material handling carts and line flow, providing workplace improvements and operator training in that order. It is of interest that the work operations are well measured in total in this plant, and it is on a piece rate basis; but it was nearly impossible to pull out the materials handling and positioning portions without some technique such as work sampling. Standard data applied to the work would have been a very involved and lengthy study. Work sampling took a few days to obtain results of the needed reliability.

DETERMINING ALLOWANCES FOR TIME STANDARDS

When standard times include allowances for small, hard-to-measure miscellaneous work elements, the accurate determination of these allowances is conveniently done by work sampling. If the miscellaneous work elements are performed at a pace different from the major work elements, pace rating must be done and multiplied into the percentages. To obtain the required reliability when dealing with allowance percentages, tens of thousands of observations are required for each kind of work suspected of requiring different allowances. Frequently a study to determine allowances leads to ideas of how to eliminate their need: a high and variable thread breakage delay incidence in a garment factory resulted in improved maintenance procedures, for example.

JOB DESCRIPTIONS

The percentage of time that a particular person, or the individuals in one job description, spend in each of several work categories is frequently vital to the job evaluation. Work sampling provides a reliable, inexpensive method of finding these percentages. It is also a good technique to use when the purpose of the job analysis is work simplification—the reduction of complex jobs into several simpler jobs, or the provision of specialists instead of versatile personnel. We have used work sampling applied to engineering jobs and broken out some of the drafting and arithmetic that were found to be consuming an un-suspected amount of time. However, it is an abuse to use work sampling measurements as the only criterion in these work simplification studies. If it is found that of ten office clerks, 30% of their time is filing, 20% relaying telephone messages, 40% typing and 10% idle, it is not necessarily true that 3 file clerks, 2 switchboard operators and 4 typists would do the work more efficiently. Many other factors must be considered in the division of work, factors that are ***not*** measurable by work sampling observations.

DETERMINING EQUIPMENT NEEDS

Another use of work sampling is the determination of the degree of use of equipment, with the goal of ascertaining equipment needs, or balancing equipment utilization with manpower, product, or customer waiting time. Activity categories of the equipment are usually defined in terms of time in operation, in setup, being maintained, being repaired, idle—no operator, idle—waiting adjustment, idle—no work and other categories of specific interest. Material handling equipment usually is observed as moving—loaded, moving—empty, waiting to load, waiting to dump, serving as temporary storage, as well as some of the other mentioned categories.

Frequently equipment utilization follows a cyclical pattern, and must be plotted against time over the length of the cycle, or several cycles. We have seen work sampling come in for considerable abuse because of neglecting the cyclical pattern of needs, and reporting that with, say, 80% utilization only four machines were needed, when in actuality at certain times of the month eight machines were necessary. Properly used in instances such as these, work sampling would have shown the cyclical pattern and perhaps suggested some work on scheduling to reduce the peak needs. Although many times job cost records, check out slips, or other records of machine utilization are available, we use work sampling to determine unavailable time such as maintenance, and unavailability caused by scheduling, such as the "idle—no operator" category.

In questions of equipment utilization we surely prefer to measure, observe, or record the incidence of the actual needs for the equipment. The sampling of how much the equipment is used is not as valuable as knowing how much it could or should be used. We have applied this to a charter airline operation, for example, and optimized number of available aircraft so as to result in a utilization of only 69% during *peak* periods.

An application of work sampling was the determination of how many "Hough loaders" (mobile scoop shovels) were needed at a lead smelter. We used both work sampling to determine availability and a record of lost time at the furnaces due to waiting for the loads. We also have used work sampling studies of equipment use to determine the expansion of sales possible with present equipment, in job shop and custom work when no work standards were available. Of course we had to assume a product mix and a scheduling interference factor, independent of the work sampling results, and our predictions were as much dependent on the accuracy of these assumptions as on the work sampling results.

DETERMINING MANPOWER NEEDS

The determination of how many and what kind of personnel are required to accomplish a workload is another use of work sampling, particularly when the workload is highly diverse or is considered economically "unmeasurable". For example, we observe the activity of 100 electronics technicians, testing varied and unique complex electronic equipment. Assume we find they are performing skilled work 30% of the time, acting as an unskilled helper to another technician (watching for lights, lifting equipment, holding ladders, etc.) 30% of the time, and idle 40% of the time, it would be a real abuse of work sampling to say we needed 30 technicians and 30 helpers instead of 100 technicians. The same comments about cycles of need, balancing of cost of over-capacity with cost of non-availability, and scheduling problems apply to manpower needs as well as to equipment needs. A further complication is that pace rating is sometimes used with the observations. That is, we might observe an average pace of 90%, and therefore conclude that only 27 technicians and 27 helpers would be needed if they were all working at a normal pace—a hazardous conclusion. The data in the example should lead us to investigate the use of helpers and make us aware of our average "over-capacity", but they cannot tell us the proper number of personnel.

MEASURE OF LABOR EFFECTIVENESS

Work sampling has been used to measure overall effectiveness. Activities are categorized as "effective" —such as productive work, and "ineffective"—such as delays or rework. Records of the per cent of effective time are kept, trends are noted, and supervisors are given goals of per cent effectiveness. There are many hazards encountered in so doing. When the observations are made for this purpose by members of the Industrial Engineering department, the Industrial Engineers are put in the awkward position of telling supervision what they "should know"—how their people are spending their time. They may be acting more as "snoopers" than as industrial engineers.

A suggestion has been for the supervisors to make the observations. This works well for the purposes of methods improvement, but labor cost control is a more delicate matter. Improvement is too easily shown spuriously—by making it a goal that everyone looks busy. Another hazard is the difficulty of taking *really* random unbiased samples. The anticipation of an activity, or the brief delay of an observation, a few seconds one way or the other, can significantly change the work sampling results.

The making of work sampling observations by supervision, for any purpose, does provide a systematic way for the supervisor to find out and appraise what his people are doing. As one supervisor said, "Probably the most immediate benefit was the enforced, periodic look at each employee, by his foreman, several times each day." This is a quote from RICHARDSON'S and HEILAND'S book "WORK SAMPLING" (McGRAW-HILL) which is an excellent text on how to do work sampling.

For the measuring of labor effectiveness, we prefer to use methods more direct than work sampling. For work sampling results to reflect effectiveness, it must be assumed that the quantities of productive work performed remain stable—measures such as customers serviced, direct labor standard hours maintained, ton-miles flown, dollars of sales, square feet of building completed, column inches of display ads set. Our preference is to relate labor cost directly to these measures.

section 9

MODEL OF AN ELEMENTARY INDUSTRIAL PROCESSING SYSTEM

by **BURTON GRAD**
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Having graduated from Rensselaer Polytechnic Institute in Management Engineering, Mr. Grad began his career as an engineer with the General Electric Company. He spent some ten years with that Company serving in such positions as Inventory Control Specialist, Production Control Supervisor, Research Specialist and Technical Counselor.

He is a member of the Association for Computing Machinery and The Institute of Management Sciences. In addition he has authored several professional papers.

A MODEL OF AN ELEMENTARY INDUSTRIAL PROCESSING SYSTEM

by Burton Grad

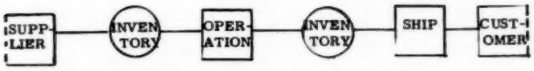
Programming Systems, International Business Machines Corporation

THE DESIGN of an industrial information processing system involves an ability to understand the structure of the physical system being controlled. This type of understanding is essential if reasonable and effective control rules are to be determined and applied. To this end it seems pertinent to be able to model or simulate the behavior of a particular proposed information processing system to see if it will perform in the way that you wish. However, to simulate the performance of an information processing system implies a terminology and format for expressing the control rules and describing the physical system being controlled.

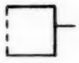
This paper will present a proposed terminology and format for such a representation and will illustrate the use of these ideas in the context of a simple example. As a clear corollary it would seem logical that a generalized simulation language structured in this way might prove highly beneficial to those charged with the information systems design.

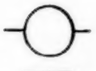
Suppose we try to describe a simple manufacturing business which has but one operation, one product model, a single source of supply and just one customer. A flow chart of the physical flow in such a business might appear as follows in Fig. 1.

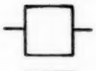
Fig. 1

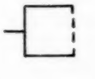


The flow of material is from left to right. There are six *Stations* in the system with each of the different types of stations being represented by a different symbol:


represents a material *source* external to the controlled system.

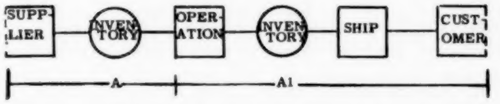

represents an *inventory* of a product model or a material.


represents an *operating station* which in some way transforms material.


represents a *customer* who is essentially a product "sink" and is external to the controlled system.

The status of the system from a purely physical standpoint can be described at any point in time by defining the number of product or material units at each station within the controlled system. To aid in expressing this we have numbered the stations as shown on the next page in Fig. 2, and identified the "product" which, of course, changes identity after the "make" operation.

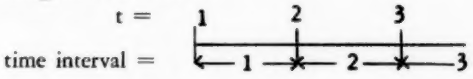
Fig. 2



We can speak of the "Raw" Inventory at the Inventory Stations and the In-process Inventory at the Operating Stations. Hence, the values I^2_A, I^3_{A1}, I^4_{A1}, I^5_{A1} are required to define the current status of the physical system.

I^s_m means the Inventory at Station s of product model m. To introduce the time concept I^s_m is always defined at a particular point in time, generally represented by t. Hence, $I^s_{m,t}$ would be the general format for describing the physical status of the business at the beginning of time interval t.

The first step beyond this static representation is to introduce the factors which will transfer the system from its state at t = 1 to its state at t = 2. Essentially, we need a record of all the movement between stations during time interval 1.



This can be done by defining a set of shipments to represent this movement. Using H to stand for shipments (S is used later for another factor,) $H^2_{A,1}$ means the shipment from Station 2 of product A during time interval 1.
Hence $H^1_{A,1}$, $H^2_{A,1}$, $H^3_{A1,1}$, $H^4_{A1,1}$ $H^5_{A1,1}$ are needed to completely itemize all physical events which take place during time interval 1. The general form is $H^s_{m,t}$.

On this basis we can define

$$I^2_{A,2} = I^2_{A,1} + H^1_{A,1} - H^2_{A,1}$$

To generalize this relationship we need to introduce the succeed-precede concept.

Station 1 is said to precede Station 2 if its output passes to that station either directly or indirectly. In our simple business Station 1 precedes Station 2 and Station 3. Succeed is the opposite of precede. In other words Station 3 succeeds Station 2 and Station 1. These relationships are summarized in Fig. 3.

Fig. 3

Precede (-)
Succeed (+)
Relationships

Station no.	1	2	3	4	5	6
1	0	-1	-2	-3	-4	-5
2	+1	0	-1	-2	-3	-4
3	+2	+1	0	-1	-2	-3
4	+3	+2	+1	0	-1	-2
5	+4	+3	+2	+1	0	-1
6	+5	+4	+3	+2	+1	0

The number in the intersection indicates the relationship between the two stations. For example the first row indicates that Station 1 precedes Station 2 by 1 stage.

$H^{s:-1}_{m,t}$ would be interpreted to mean the shipments of model m during time interval t from a station 1 stage before (preceding) Station s.

The Inventory equation would then have the following form:

$$I^{s}_{m,\,t+1} = I^{s}_{m,\,t} + H^{s:-1}_{m,\,t} - H^{s}_{m,\,t}$$

This is satisfactory except for the case of transforming a material into a product model which still needs to be explained. This can be shown by a "Gozinto" Table like Fig. 4.

Fig. 4 *Gozinto Table*

Station	1	2	3	4	5	6
"Gozinto" Material - (g)	A	A	A	A1	A1	A1
Output Product - (m)	A	A	A1	A1	A1	A1

In the Gozinto Table m is identified as the "output" model at the station under consideration. The Gozinto material (g) may be the same model or it may be a different input material. For example, at station .3 the model identity is A1 but the "Gozinto" material identity is A. Therefore the general equation should be:

$$I^{s}_{m,\,t+1} = I^{s}_{m,\,t} + H^{s:-1}_{m:g,\,t} - H^{s}_{m,\,t}$$

Where m:g means the "Gozinto" material g for model m at succeeding station s. To show this, s = s: -1 hence s: +1 (which is the succeeding station) = s. To illustrate:

$$I^{3}_{A1,\,2} = I^{3}_{A1,\,1} + H^{2}_{A,\,1} - H^{3}_{A1,\,1}$$

This fully defines a manner for computing the physical state of a system giving the initial state ($I^{s}_{m,}$ n) and the shipments between stations during the time interval ($H^{s:}_{m,}$ t),

These values, however, have certain built-in constraints. For example the amount shipped from a station can obviously not exceed the inventory at that station at the beginning of the time interval, assuming that any receipts during the period would not be in time to be operated on. We might express the first part of this constraint by stating that:

$$H^{s}_{m,\,t} \leqslant I^{s}_{m,\,t}$$

This establishes the limitation of initial inventory available but it does not give recognition to the possibility of immediate access to more input material. This can be done by defining the cycle time required to provide a shipment from a station.

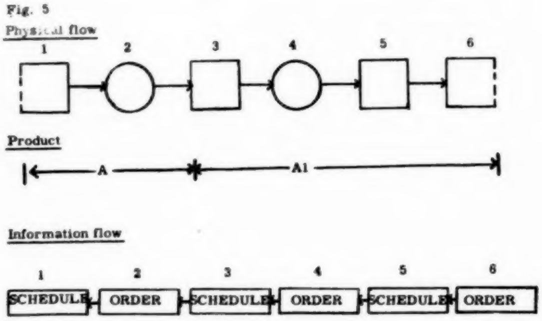
C^{s}_{m} Cycle time at Station s for model m.

If s is an inventory station then C^{s}_{m} can be O, so that the next Station (s: +1) may receive additional input material in time to be of direct use during that period. This implies a negligible informaton cycle time which is the time it takes to communicate a material requirement to the preceding station (s:-1). So we might repeat the constraint in this way:

$$H^{s}_{m,\,t} \leq I^{s}_{m,\,t} + I^{s:-1}_{m:g,\,t}$$

So far we have just described the operation of a physical system with no thought of product demands, decision rules or even an explicit recognition of the role of information processing. Let's modify the original flow chart to bring into play certain of these features as in Fig. 5:

Fig. 5



This "phantom" information system has certain obvious properties. The information flow is essentially the reverse of the physical product flow. There is one to one mapping of stations on decision elements. There are only two types of decision elements: Order and Schedule. An Operating Station and a Source become Schedule decision elements; the other two become Order elements. For the sake of clarity, we will use the same station code numbers to identify the decision elements as were used for the physical station itself. The meaning will be obvious from the context.

The first decision element is that of Order. This function is concerned with determining the quantity desired from the preceding station. Without getting involved in the structure of a particular rule, we can see that $R^{s}_{m:g,\,t}$ (the order quantity from station s for the gozinto material g for model m ordered during time interval t) will depend on present inventory status, current orders and unfilled requests from the succeeding stations, forecast of future requirements, preceding station cycle time, etc. Each station has the opportunity of placing an order on any directly preceding station (s:-1) during the preparatory phase of a time interval.

To examine the meaning of the second decision element, Schedule, it will be helpful to review the sequence of events in the system.

At the very beginning of a time interval (t) we know the inventory status of each station is ($I^{s}_{m,\,t}$). Then an order is received by Station 5 from Station 6 ($R^{6}_{A1,\,t}$). Station 5 reviews its own inventory and that of Station 4 to determine the maximum quantity of the requested model which it can process. For simplicity, let's assume that the cycle for shipping is just one time interval so $C^{5}_{A}1 = 1$. We can also assume that there is a trivially simple scheduling rule:

$$S^{5}_{A1,\,t} = \min \left\{ R^{6}_{A1,\,t},\quad (I^{4}_{A1,\,t} + I^{5}_{A1,\,t}) \right\},$$

where $S^{5}_{A}1,t$ represents the scheduled quantity at Station 5 for period t and min stands for minimum of.

This rule implies no consideration of unfilled orders about which more later. For now we can imagine the customer reordering any unfilled requirements at the beginning of the next time interval (t+1). We can also simplify the equations by precluding an Operating Station from having inventory not assigned to specific orders. On this basis $I^{5}_{A1\,t} = 0$; there is no available inventory. For instance, under this restriction there would not even be any actual inventory remaining at the beginning of the next period unless $C^{s}_{m} > 1$

With this approach the general scheduling equation could be reduced to:

$$S^{s}_{m,\,t} = \min \left\{ R^{s:+1}_{m,\,t},\ I^{s:-1}_{m:g,\,t} \right\}$$

We can also assume that

$$H^{s}_{m,\,t} = S^{s}_{m,\,t} \quad \text{for } C^{s}_{m} = 1.$$

This simply means that shipments at the end of a period will always equal the quantity scheduled at the beginning of a period if the Cycle time is one time interval. We have a deterministic, perfectly performing facility.

So Station 5 decides to make $S^{5}_{A1,\,t}$ based on orders received and the prior station's inventory status. It, of course, needs immediate delivery of the gozinto material if it is to make shipment by the end of the time interval. The quantity needed at Station 5($R^{5}_{A1,\,t}$) is ordered from the preceding inventory Station 4.

Station 4 supplies the material right away ($H^{4}_{A1,\,t}$) and then makes its own ordering decision. Here again let's envision a trivially simple ordering rule:

$$R^{s}_{m,\,t} = H^{s}_{m,\,t} \quad \text{where for the case of } C^{s}_{m} = 0 \text{ and } C^{s:+1}_{m} = 1$$

$$H^{s}_{m:g,\,t} = S^{s:+1}_{m,\,t}$$

In other papers we will eliminate these highly restrictive assumptions, but for the sake of explanation and understanding, I believe these simple rules are most desirable.

Station 4 will transmit its order ($R^{4}_{A1,\,t}$) to Station 3 which will schedule the required quantity. If $C^{3}_{A1} = 2$ this would mean that Station 4 would not receive delivery until the end of the t + 1st period. In other words, we'll have to make sure that Station 4 has a properly determined safety stock to be able to cover its expected needs at the beginning of period t+1.

But Station 3 may not even be able to supply the entire order for Station 4 since it is itself restricted by the inventory at Station 2. Conversely it may have some material half-way through the process that it started during period t-1. We have made the statement that no quantities are scheduled on order speculation so we can assume that any $S^{3}_{A1,\,t-1}$ would be in response to an $R^{4}_{A1,\,t-1}$.

If we define $S^{s}_{m,\,t}$ to mean the quantity to be started at the beginning of interval t then we can say (assuming perfect performance):

$$H^{s}_{m,\,t+c-1} = S^{s}_{m,\,t} \quad \text{where } C = C^{s}_{m}$$

The quantity shipped at the end of the time interval t+c-1 will equal the quantity started at the beginning of t. If c = 1 then this degenerates into:

$$H^{s}_{m,\,t} = S^{s}_{m,\,t} \quad \text{as for Station 5}$$

If $C^{3}_{A1} = 2$, then $H^{3}_{A1,\,t+1} = S^{3}_{A1,\,t}$.

We can say then that:

$$S^{3}_{A1,\,t} = \min \left\{ R^{4}_{A1,\,t},\ I^{2}_{A,\,t} \right\} = R^{3}_{A,\,t}$$

This order request R^{3}_{A} t is immediately transmitted to the preceding inventory Station 2 which responds by delivering the required material:

$$H^{2}_{A,\,t} = R^{3}_{A,\,t}$$

This brings out a key aspect of the definition. An inventory station does no processing and therefore requires no time. Where there is a function to be performed it is necessary to distinguish between the inventory station and an operation station.

Next Station 2 goes through its ordering procedure; we could think of $R^{2}_{A.t}$ $H^{2}_{A.t}$ with appropriate provision having been made for safety stock to cushion the demand variance over the lead time interval.

Let's now introduce the idea of an information lag.

Suppose the order from Station 2 takes 1 time interval to arrive at Station 1 and suppose Station 1 will take 2 time periods to process the material and 1 time period to transport it to Station 2. If we simply add these factors together (1+2+1) we obtain a lead time of 4 time periods.

We need to represent separately the ideas of information cycle, processing cycle, transportation cycle and lead time since each is used in a somewhat special way in describing an operating system. This can be done by adding a second subscript to the C^{s}_{m} term making it:

$$C^{s}_{m,i} = \text{Information Cycle}$$

$$C^{s}_{m,p} = \text{Processing Cycle}$$

$$C^{s}_{m,r} = \text{Transportation Cycle}$$

$$C^{s}_{m,d} = \text{Lead Time}$$

In the example described,

$$C^{1}_{A,i} = 1$$

$$C^{1}_{A,p} = 2$$

$$C^{1}_{A,r} = 1$$

$$C^{1}_{A,d} = 4$$

This enables us to think of $S^{1}_{A.t+1}$ being in response to $R^{2}_{A,t}$ and $H^{1}_{A,t+2}$ resulting from $S^{1}_{A}\ t+1$.

Because of the transportation cycle, we should now differentiate between a shipment and a receipt so it is useful to define a receipt as an Arrival $A^{s}_{m:g,t}$. In this case $A^{2}_{A,t+3}$ should reflect $H^{1}_{A.t+2}$. The generalized formulas would now appear for the deterministic case as:

$$S^{s}_{m:g,\ t+c(i)} = f\,(R^{s:+1}_{m:g,\ t}$$

$$\text{where } c(i) = C^{s}_{m:g,\ i}$$

$$H^{s}_{m,\ t+c(p)-1} = S^{s}_{m,\ t}$$

$$\text{where } c(p) = C^{s}_{m,\ p}$$

$$A^{s:+1}_{m:g,\ t+c(r)} = H^{s}_{m:g,\ t}$$

$$\text{where } c\ (r) = C^{s}_{m:g,\ r}$$

or,

$$A^{s}_{m:g,\ t+c(d)-1} = f\,(R^{s}_{m:g,\ t})$$

$$\text{where } c(d) = C^{s}_{m:g,\ d}$$

$$c(d) = c(i) + c(p) + c(r)$$

Station 1 may have its own problems in terms of raw materials inventory, scheduling capacity, and so on, but we will treat the supplier, for now as though it were an infinite, deterministic source so that:

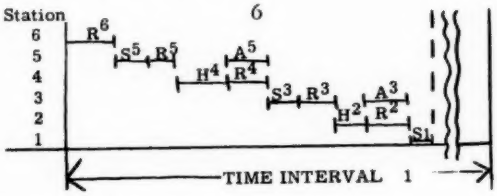
$$S^{1}_{A,\ t+1} = R^{2}_{A,\ t}$$

and (to take into account the information lag)

$$A^{2}_{A,\ t+3} = R^{2}_{A,\ t}$$

Diagrammatically the *preparation* period would appear as shown in Fig. 6.

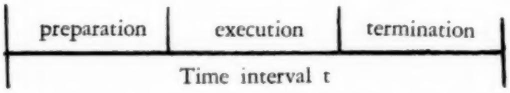
6



Where S^{1} refers to scheduling the order placed by Station 2 during the previous time interval.

At the other end of the time interval, the *termination* period, there is no meaningful sequence of shipments and arrivals, but there is an order of calculation. Each non-inventory station ships the quantity it had scheduled to complete by the end of that time interval. Each station next computes its arrivals based on shipments and transportation cycle. Then each inventory station calculates the inventory status which it will have at the beginning of the next time interval. The three portions of a time interval are shown in Fig. 7.

Fig. 7



During the *execution* period each station carries out its assigned task.

One information concept still needed is the unfilled order logic. Let stand for the unfilled orders at station s for model m at the beginning of time interval t. So,

$$U^{5}_{A1,\ 2} = U^{5}_{A1,\ 1} - H^{5}_{A1,\ 1} + R^{6}_{A1,\ 1}$$

In effect, the unfilled orders are an "inventory" of open orders to which the "receipts" are the orders from the succeeding station and the "withdrawals" are the shipments to that station. We can consider the unfilled orders being calculated during the termination period of a time interval after the shipments have been made and arrivals computed.

To illustrate further since we have considered that each operating station transmits an order $R^{s}_{m;g,t} = .S^{s}_{m,t}$, and each inventory station makes immediate shipment, an inventory station could calculate its unfilled orders during the preparation period of the time interval. This can be quite significant, though, in that an inventory station's ordering rules can be made a direct function of unfilled orders.

The concept of unfilled orders brings in another factor: the ordering station's acceptance of a delivery delay. For this discussion we will simplify by assuming full willingness to accept any delivery delay for the order placed, though such delays may have their influence upon future orders. Unfilled orders are calculated as viewed by the supplying station. The converse would be for the ordering station to keep track of its unfilled requests.

$$V^{s}_{m:g,\,t+1} = V^{s}_{m:g,\,t} + R^{s}_{m:g,\,t} - A^{s}_{m:g,\,t}$$

which is directly analogous to the unfilled orders approach. Unfilled requests must be calculated after determing shipments and arrivals. As a rule, inventory will be used to satisfy unfilled requests first at the beginning of the next time interval; any remaining inventory will then be applied to new orders received.

The unfilled order equation can be generalized further if we withdraw the implied assumption that the information cycle time is zero. This requires defining another factor, orders received.

$O^{s}_{m,t}$ are the orders received at station s for product m during the preparation period of time interval t.

$$O^{s}_{m,\,t+c(i)} = R^{s:+1}_{m,\,t}$$

where c (i) again means $C^{s}_{m,i}$ we can now restate the unfilled order formula:

$$U^{s}_{m,\,t+1} = U^{s}_{m,\,t} + O^{s}_{m,\,t} - H^{s}_{m,\,t}$$

We can also consider the unfilled orders which have *not* yet been scheduled. This would be:

$$U^{s}_{m,\,t} - \sum_{a=t}^{a=t-c(p)+1} S^{s}_{m,\,a}$$

Summary

To review the development in this paper, a set of terms has been established which describes the changes that occur during a time interval from both a physical and an information viewpoint. These systems change factors include:

$H^{s}_{m,\,t}$ = Shipments from Station s

$A^{s}_{m,\,t}$ = Arrivals at Station s

$R^{s}_{m,\,t}$ = Orders placed by Station s

$S^{s}_{m,\,t}$ = Amount Scheduled at Station s

$O^{s}_{m,\,t}$ = Orders Received by Station s

$H^{s}_{m,t}$ $A^{s}_{m,t}$ and $O^{s}_{m,t}$ result from the operation of the system and, though influenced by the various decisions, are not themselves decision elements. The other two are decision elements except for s: + 1 non-existent (e. g. a customer station).

Secondly, there are certain systems "constants":

$C^{s}_{m,\,i}$ = Information Cycle Time

$C^{s}_{m,\,p}$ = Processing Cycle Time

$C^{s}_{m,\,t}$ = Transportation Cycle Time

Third, there are terms which enable us to express both the physical and information status of a system at the beginning of a time interval. These systems status variables are:

$I^{s}_{m,\,t}$ = Inventory at Station s

$U^{s}_{m,\,t}$ = Unfilled Orders (received by Station s)

$V^{s}_{m,\,t}$ = Open Requests (placed by Station s)

There are also 3 key relationship concepts which have been expressed:

(1) Precedence
(2) Gozinto
(3) Time interval breakdown into preparation, execution, termination

A variety of techniques have been developed to overcome the simplifications in this model. They will be discussed in later papers. Included will be consideration of:

(1) Assembly structure including multiple supuly and multiple destination stations.
(2) Alternate routing.
(3) Non-stock inventory stations
(4) Quality variance including spoilage.
(5) Non-infinite sources, multiple suppliers for the same product.
(6) Variable cycle and lead time.
(7) Order aggregation
(8) Multiple period scheduling intervals
(9) Various scheduling rules including consideration of capacity limitations, employment stability
(10) Various ordering rules
(11) Safety stock considerations
(12) Variable processing times including setups
(13) Transportation stations
(14) Effect of various dispatching rules
(15) Stochastic production and supply rates

This paper just illustrates the initial work in an area which requires extensive further research and development.

section 10

CONTROL OF MACHINE MEMBER POSITION, DISCRETE VS. CONTINUOUS

by **JAMES R. WALKER**
Research Director

GEMCO ELECTRIC COMPANY

Mr. Walker graduated from Wayne State University in 1941 with a B.S. degree in Electrical Engineering. After a short period as a Design Engineer at ITE Circuit Breaker Co. he became a Research Engineer at Excello Corporation in Detroit, working on electronic control systems for various machine tools. In 1945, he became a Teaching Fellow at the University of Michigan, receiving the M.S. degree in Physics in 1946. While continuing work on the Doctoral degree in Physics, Mr. Walker taught at Wayne University in Detroit from 1946 to 1949. From 1949 to 1956 he was the Director of Engineering Research at this University.

He was appointed Director of Research at Gemco Electric Company in 1956, where he has been concerned with development of various control devices and control systems, for use in machine tools.

CONTROL OF MACHINE MEMBER POSITION — DISCRETE VS. CONTINUOUS

by JAMES R. WALKER

Director, Gemco Electric Company

INTRODUCTION

IN THE past two decades, the industrial engineer has witnessed a gradual but continuous conversion of machine control systems from preponderantly mechanical linkage and positive control to now principally error position repeatback electrical and electronic control systems. This has been particularly true in machine tools whose primary function is to produce machine parts and operations thereon with great accuracy and conformity. Close tolerances on machine parts imposed by the modern aircraft industry has necessitated the development and use of machine tools capable of repetitiously producing such components with a minimum of observation and adjustment.

Excluded from present consideration are processes involving large quantity production of machine components and assemblies whose size tolerances are not minimal and which are only infrequently changed in essential detail.

In this category can be included automobile engine components, and lesser fabricated items such as household devices.

Even though certain techniques of measurement, data repeatback, and compensation have been utilized in these industrial processes, it is noted that by far the greatest contribution to fully automatic machine control has been made on machine tools intended for limited production items.

Applications of automatic machine tools possessing widely varying input data and operation capability have been restricted to limited production industries due to the unfeasibility of constructing for their use a machine whose sole purpose is to produce a single component, as is the case in the auto industry.

Use of machine tools capable of reliable and accurate member position control in response to either direct operator supervision or recorded input positional data are usefully being employed for the processes of hole drilling, tapping, boring, and contour milling operations.

It is one of the present purposes to consider the realm of application for control means suitable to the two principal types of machine control—discrete and continuous.

DISCRETE CONTROL OF MACHINE MEMBER POSITION

This mode of control shall deal with the means employed for achieving member motion from one point to another point on a given reference axis of a machine by measured multiples of a given incremental magnitude.

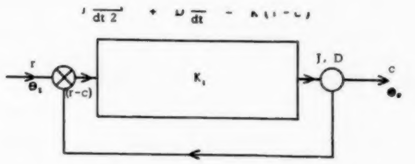


Fig. 1 Basic Closed Loop Control System

c = Controlled Variable
r = Reference Input

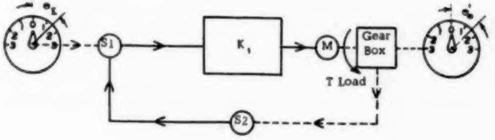


Fig. 2 Position Control System

Examples of machine operations employing this mode of control are those of drilling, tapping and boring of holes in machine castings. The order of accuracy required for these operations is dependent upon the ultimate use of the produced item. However, a certain tolerance magnitude can be given for drilling and tapping amounting to plus or minus .001 in., while with boring the tolerances are often narrowed to plus or minus .0001 in.

It should be anticipated that a wide difference exists between the physical response requirements imposed upon a given machine capable of repetitiously positioning one of its movable members to a tolerance of plus or minus .0001 in. and that for a machine whose tolerance is plus or minus .001 in.

Actually, this is the case. However, it often happens that operations requiring widely varying tolerances must be completed on a casting while it resides on a single machine.

Consequently it is necessary that the machine tool be designed to incorporate member response and control system capability which will yield in combination of a member positioning accuracy less than the allowable operational tolerances.

MACHINE MEMBER REQUIREMENTS

In order that a machine tool can be used for operations on large castings, in some cases weighing one or more tons, as well as smaller castings, often weighing less than one pound, it is important that associated tables and transverse slides be designed for support of maximum expected loads without distortion or deflection. Accordingly, the weight of table plus cross slide, constructed with appropriate webbing, often weighs several tons without work load present.

Although the first concern in design of a machine has centered about the consideration of member stability with temperature and minimization of reference surface deflection with load, a second consideration must deal with motion of member supporting structures from one point to another by a discrete amount.

To accomplish this positioning with minimal disturbance to the surrounding structure and subject work casting, it is important that the guiding surfaces or machine slides present a uniformly and small friction component.

In this regard, three means are used frequently for minimizing and providing constant frictional losses between positioned and fixed members of a given machine tool, forced oil lubrication, oil lubrication-air lift, hardened way-rollers.

Another component of a machine whose physical characteristics contribute to final machine plus control response and positional accuracy is the regulating or motion translating means used to convert rotational motion of the primary power source to linear motion of a machine member.

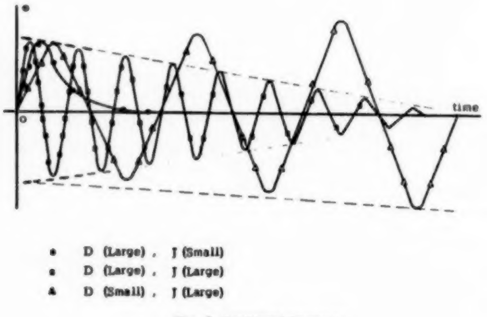


Fig. 3 Positional Response

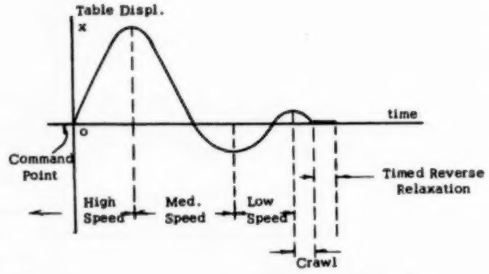


Fig. 4 Open Loop Positioning

This conversion can be accomplished by means of a lead screw-nut arrangement or a hydraulic ram mounted under the movable member of the machine.

From the standpoint of machine dynamics, it is clear that machine parameters contributing directly to an appreciation of control dynamics are:

a. Machine member mass (inertia).
b. Frictional forces between moving members.
c. Friction and inertia of positional translating means.

Ideally from a control standpoint it is desirable to minimize all three above listed factors due to the reduction which can be effected in prime motor horsepower, and rotor inertia.

This consideration follows from the basic control equation for a machine member which represents the summation of torques on a generalized load connected to a positioning or regulating device deriving its control excitation from a torque or force amplifier.

$$J \cdot \frac{K_m}{K_T} \frac{d^2\theta_o}{dt^2} + \frac{d\theta_o}{dt} + K_v \theta_o = K_v \theta_I \quad \ldots\ldots (1)$$

J is the inertia of load
$f_m = \frac{K_T}{R_m}$ is a frictional constant
$K_v \theta_o$ is the torque output of the amplifier

In block representation such a simple control system can be shown as in Fig. 1.

To illustrate the meaning of relation (1), consider the solution of this differential equation for the angle θ_o which for example can represent the angle between a reference point on a signal input shaft and another reference point on the shaft of a controlled torque motor as illustrated in Fig. 2.

Such a solution in total form is,

$$\theta_o = \Theta \cdot \frac{\omega_n}{(1-\zeta^2)^{1/2}} \cdot e^{-\zeta\omega_n t} \cdot \sin\left[(1-\zeta^2)^{1/2} \cdot \omega_n t\right] \quad \ldots\ldots (2)$$

where the factor Ⓗ represents the steady state displacement angle of the regulated member

$$Ⓗ \simeq \Theta_I$$

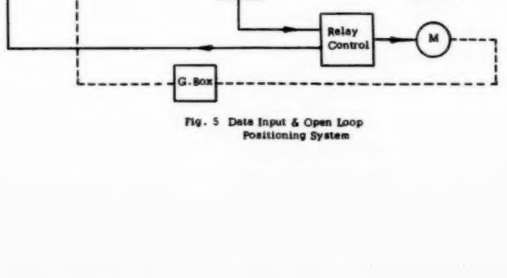


Fig. 5 Data Input & Open Loop Positioning System

ζ is a decremental factor dependent upon the friction of the system $(1-\zeta^2)^{1/2}\omega_N$ is an angular velocity depending for its magnitude on the accumulated inertia of the system.

Inspection of (2) relates the existence of two parts,

a. The amplitude factor $\frac{\omega_N}{(1-\zeta^2)^{1/2}} \cdot e^{-\zeta\omega_N t}$

b. The oscillotory factor $\sin[(1-\zeta^2)^{1/2}\omega_N]t$

According to the relative magnitudes of J and f_m will depend the type of positioning cycle occurring in the member following an input angle disturbance. The three cases illustrated in Fig. 3 can occur for different values of system inertia and friction.

Here can be seen the type of response that is achievable from a closed loop control system when it is used with a machine including various ranges of physical parameters.

A second and basically important type of control system can be used for controlling the position of machine members by opening the control loop; i. e., removing the repeatback device S_2 from Fig. 2. This change results in a different response equation,

$$\theta_o = \Theta' \cdot \frac{\omega_N}{(1-\zeta^2)^{1/2}} \cdot e^{-\zeta\cdot\omega_N t} \cdot \sin[(1-\zeta^2)^{1/2}\omega_N t] , \Theta \neq \theta_r$$

The important result in removal of the loop closing "position repeatback data" is the failure of the input data device to know how far it has positioned the output member.

Although it would seem from first consideration that the practicability of open loop control would be most unsuitable for use in machine member positional systems requiring repeatable accuracies of plus or minus .0001 in. it has nevertheless been shown that such is not the case.

This has been amply illustrated by certain boring machines using power positioning in both table and slide. These machines employ a fixed cycle of relay-motor control allowing the machine member to be positioned at a rapid rate until a point close to the final command or readout point is reached, whereupon the speed is reduced on the drive motor and a gear change is made in the gear box. Here the motor causes referenced machine member to move to the command position under reduced speed until a position pickoff device signals arrival at the command position.

Although it has happened too late to stop the drive motor at required machine position, the motor is now reversed and the gear box changed to a higher ratio. Progression of the member back toward the command point at a greatly reduced speed now allows this member to be stopped very near but slightly beyond the command point. The distance beyond the command point to which the machine member travels is dependent upon its associated inertia plus that of the load and the summation of system frictional components. This type of cycle is illustrated in Fig. 4.

Here the final position attained in the open loop cycle includes a relaxation region which is used only with lead screw-nut translational systems. Its use is to remove the lead screw from close constant contact with the lead nut so the driven machine member can be effectively locked without further change in position.

This removal of the possibility for member repositioning after locking as well as achievement of a controlled oil film (friction) approach to the command point, results in an overall system positional accuracy repeatable within plus or minus .00005 in.

A comparison of the related open loop cycle of positional control used in several presently manufactured boring machines, with the closed loop positioning cycle described previously, yields certain points of basic similarity.

For example the damped oscillatory cycle of positioning is common to both methods and the dependency of approach to the final command point is dependent upon system friction. However, it must be noted that the closed loop system will finally achieve a minimum static error regardless of system friction with a reduction of the system damping period, while the open loop system will position with minimum and constant command point error only if the friction remains constant.

A review of requirements imposed upon a closed loop machine control system necessary to achieve minimal static errors in position with adequate stability indicates the necessity for use of the following machine components

1. Air lift machine ways.
2. Zero backlash gear path between motor and final machine member.
3. Ball-Nut drive with zero backlash for machines presently using lead screw-nut drives.
4. Minimization of deflection in lead screw-nut gear system to motor.

Analysis has shown that the average cost of machine plus control system capable of exhibiting positional errors of the order plus or minus .0001 in. and employing closed loop control is 4 times that for an open loop system. (For both means of control considered it should be stated that a discrete type of data input device such as that shown in block form Fig. 5 is used.)

Because of a seemingly unfavorable cost comparison between the two types of systems considered it is quite conclusive that a closed loop control system even with its significant advantages cannot be economically justified for some tool shop operations.

Although certain control manufacturers will quote control system costs for point to point closed and open loop control which are essentially the same, it must be remembered that the necessity for use of a more expensive machine tool construction accounts for the factor of 4 given for the overall difference in cost between the two systems. The principal advantages gained in the use of the closed loop control system is that it can also be used for continuous position control of machine members and that its positioning time is shorter than for the open loop control by a factor of 5 to 10. Fur-

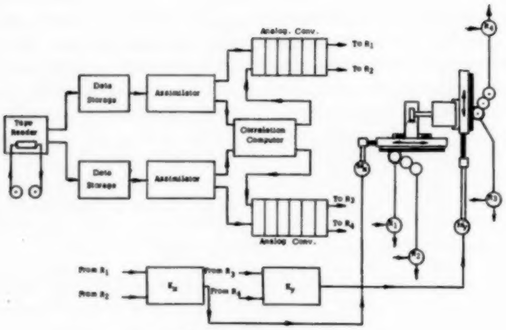


Fig. 6 Two Axis Contour Milling Control System

ther, if a continuous control system combined with correlation of cross-axis control means and data storage equipment then it can be utilized for contour milling of complex geometrical components.

CONTINUOUS CONTROL SYSTEMS

The type of data input device employed in either a discrete or continuous control system can be the same and has assumed the form of multiple channel magnetic tape, perforated cards, single or multiple channel perforated tape.

Machine assimilation of a command data from such an input device concerning the contour of a given machine component, must be based upon several factors. Among these are

1. Symmetry of part.
2. Variation and rate of variation of surface curvature in planes of symmetry.
3. Tolerable variation in final dimensions.
4. Required rate of stock removal.
5. Type of material to be removed.

A closed loop control system must be used on each of the principal axes of symmetry for a given machine when the information derived from a data input device occurs in digital form. Accordingly, this closed loop control system further imposes certain requirements on machine member positioning means and the means of lubrication employed. It has already been indicated that a necessity exists for the following machine characteristics:

1. Minimum and controlled friction between member surfaces.
2. Zero backlash in all gear or screw drives.
3. Minimum inertia in movable members
4. Minimum deflection of all movable members.

Observance of these machine factors in design of a contouring machine for example will allow full utilization of high performance servo systems for control of member position in all axes of symmetry.

High performance servo control of member position will include such important characteristics as minimum dynamic and static position error. As a consequence of these machine control characteristics, it is then possible to achieve accurate and responsive utilization of digital data pertaining to machine component geometry.

Reference to Fig. 6 will allow a study of the block diagram representing the principal components of a continuous control system arranged for contour milling in two axes. The principal differences to be observed between this system and a point to point system employing closed loop control are:

1. Necessity for data storage and assimilator repeat-back elements in continuous data system.
2. Requirement of cross-axis or correlation control signal paths for the continuous system.
3. Tool curvature computer and control means.

Differences (1) and (2) above can be eliminated in systems employing low performance servo systems and slow speed data input devices. However, (3) is an essential requirement of any or all machine control systems whether they be discrete or continuous in type.

A partial solution has been attained by certain machine tool manufacturers by the use of tool handling and positioning mechanisms which are essentially open loop in control scheme. In these mechanisms, no attempt is made to control tool curvature or tool tip position with regard to a reference point on the machine or machined component.

Although tool handling mechanisms of this nature can be usefully employed on machines whose operations involve the use of soft castings (aluminum, magnesium, die cast, etc.) some question exists whether their added cost can be economically justified on machines used for processing of hard metal castings because of the necessity for frequent inspection and replacement of tools used thereon.

Until tool control systems are made available, which can provide tool point evaluation and positioning with respect to a reference point of measurement, then it is questionable whether the use of present tool handling systems, whose cost sometimes doubles initial machine cost, is justifiable except for use in aircraft and related industries.

CONCLUSION

Comparison and evaluation of the two principal means of control for machine members, discrete and continuous, and their possible application to various production machines can lead to certain conclusions dependent upon the method of evaluation employed. If an evaluation is based only upon economic necessity then it can be shown that a discrete data closed loop system for use with drilling, tapping, and boring machines, although initially more expensive, can be justified on the basis of minimized positioning time for each machine operation.

However, if the evaluation of a given machine and its control system is determined on the basis of initial cost, then the *discrete open loop* control system must be employed at the expense, as already noted, of increased positioning time. Yet another possibility exists in the choice of a machine and control system which can be effectively used to provide machine operations including all those previously cited: drilling, tapping, boring, and contour milling. In order to include this latter operation, *a closed loop control* system for *discrete closed loop* positioning can be used for continuous positioning of machine members by the addition of data storage and cross-correlation control units as already described. The addition of these units to a control system increases the initial cost by a factor of 3. Hence, it is seen that the overall initial cost of a contouring machine including *continuous closed loop* positioning control systems will, according to the multiplying factors given, yield a difference in cost of nearly ten times that for a *discrete open loop positioning* system employing digital or tape input data which is capable of controlling machine operations, drilling, tapping, boring and simple milling. Although it would appear that the logical choice, notwithstanding the high original cost, for a versatile low production machine would be a contour milling machine, there is yet a most important consideration.

At the present time, there is no standard sized contour milling machine which can provide the continuous control accuracy necessary in a boring machine (plus or minus .0001 in.) due to difficulty in achieving the idealized conditions of machine operation already described. Under this consideration, it is now quite firmly established that a contour milling machine, at least for some period into the future, should be restricted to use in contour milling only because of its wide tolerance capability. Consequently, the choice to be effected in a machine control system for a drilling, boring, or tapping machine must be made principally on the basis of machine positioning time, i. e., closed loop for short positioning time and open loop for longer settling time.

section 11

WORK MEASUREMENT & METHODS IN THE PROCESS INDUSTRY

by **JOHN M. BARKSDALE**
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Mr. Barksdale received his B.S. degree in Industrial Engineering from North Carolina State College and his M.S. degree from the University of Alabama. He is a registered professional engineer and is active in several professional and civic organizations.

He has had wide professional experience, having served in supervisory positions in Industrial Engineering, Plant Engineering and Plant Maintenance with several nationally known corporations.

section 12

W. G. SEINSHEIMER — LABOR MANAGEMENT PROBLEMS

by W. G. SEINSHEIMER
W. G. SEINSHEIMER & ASSOCIATES

Mr. Seinsheimer did his undergraduate and graduate work at M.I.T., the University of Pennsylvania and the University of Cincinnati.
He has held various positions with firms in the garment industry, including Industrial Engineer, Controller, Director of Personnel and Plant Superintendent.

After serving as Industrial Engineer Consultant with a New York firm for slightly over a year, he formed his own consulting association.
Still operating this organization, Mr. Seinsheimer spends majority of time serving as arbitrator handling all types of grievances, specializing to a great extent in Industrial Engineering type cases such as Job Evaluation and Incentives. He has served as permanent umpire for the Jeffrey Mfg. Co. and I.A.M. of Columbus, Ohio; also has been consulted by various labor unions on Industrial Engineering problems. Mr. Seinsheimer is on the panels of American Arbitration Association and Federal Mediation and Conciliation Service.

ARBITRATION OF INDUSTRIAL ENGINEERING DISPUTES

by WALTER G. SEINSHEIMER

Labor-Management Consultant and Arbitrator

TO START out properly I shall set the stage by defining the terms in the title of my address. I know I shouldn't have to define industrial engineering to industrial engineers, but as is often said during an arbitration hearing the explanation is "for the sake of the record"—"Industrial engineering is concerned with the design, improvement and installation of integrated systems of men, materials and equipment. It draws upon specialized skill in the mathematical, physical, and social sciences, together with the principles and methods of engineering analysis and design to specify, predict, and evaluate the results to be obtained from such systems." This, by the way, is the official definition of our society, the American Institute of Industrial Engineers.

Now let's turn to the term, arbitration. "Arbitration is a contractual proceeding whereby the parties to any controversy or dispute, in order to obtain an inexpensive and speedy final disposition of the matter involved, select a judge or judges of their own choice and by consent, accept the arbitrator's findings as being binding to the disputing parties and recognize the findings as being final." Since you all are, or should be, familiar with industrial engineering, I would like at this point to tell you something more about arbitration, after which I intend to bring the two fields together and describe some cases concerned directly with industrial engineers.

Labor arbitration as it is practiced today is relatively new, perhaps 25 to 30 years old, but forms of arbitration go back to the latter part of the nineteenth century in our country, but can be traced back in England to the 18th century when that country prohibited combinations of workers and provisions were made for the settlement of wage disputes by the justice courts. Actually the early arbitrations in this country concerned with what we now call collective bargaining, and the first known mention of arbitration in labor matters in the United States of America, occurs in the Constitution of the Journeymen Cabinet-Makers of the City of Philadelphia in 1829. Many other labor organizations endorsed arbitration during the last half of the 19th Century, but it was around the coal mining and railroad industries that legislation occurred not only at state but at federal level as well. I should also mention that it was not only labor organizations that took an interest in arbitration in those early days, but a number of civic organizations made up of leading industrialists such as the National Civic Federation, which was founded in Chicago to promote conciliation and arbitration. Local committees of this organization were set up in the early 1900's in New York, St. Louis, Cleveland and Boston. Actually both labor's and management's interest in arbitration grew out of serious strikes in major industries, and as a result a great deal of the arbitration in those early days had to do for the most part with determination of the terms of the labor-management agreements.

There is a lot more historical data that is of interest to arbitrators but not necessarily to you industrial engineers. During World War I many strikes occurred and caused increased interest in arbitration and also caused serious consideration of compulsory arbitration. The post World War I years brought about progress in the arbitration of disputes over the interpretation and application of contract provisions. This progress is owed to agreements and procedures worked out between the Amalgamated Clothing Workers and Hart Shaffner and Marx. Actually the apparel industry was, you might say, the foster parents of modern arbitration. It is interesting to note, however, that today there is little or no arbitration occurring between management and unions in the apparel field. Not that the grievance procedure including arbitration isn't in the contracts, it just is, I guess, that stability has been reached.

Despite the above mentioned activity the total number of arbitration cases up to 1929 were less than the number of arbitration cases that occur in one year now. The great increase and acceptance of arbitration that we have today undoubtedly originated with the growth of collective bargaining which in turn was touched off by the passing of the Wagner Act in 1935.

This brings me down to the present, and you all undoubtedly have realized, as I've briefed the history of arbitration, that there are basically 2 kinds of arbitration:

1. Arbitration of terms (usually wages) to be included in a labor-management agreement, and
2. Arbitration of disputes over the meaning and application of provisions in the agreements entered into by the parties.

The first, mentioned above, occurs only occasionally these days and usually involves utilities or basic industries. The steel industry, as you know, recently went through a long strike, and many times it was suggested that the issues be arbitrated. There also was some pressure for compulsory arbitration; however, both sides resisted this pressure for which we all, as free American citizens, should be grateful.

It is the second category, however, that is of interest to us here today, and it is this category that I wish to expand upon now.

Arbitration over the application of contract provisions covers an enormous number of subjects. The American Arbitration Association in a recent research report lists over 50 different categories of grievances. However, since I am addressing industrial engineers there is not much point in discussing such issues as discipline and discharge which include damage to company property, absenteeism, dishonesty, insubordination, refusal to perform a job assignment, intoxication, fighting, sleeping on the job or such seniority issues as lay-off and bumping, promotion and bidding rights, recall from lay-offs, computation of seniority or such other issues as vacations, holidays, union security issues, subcontracting, leaves of absence, call-in and reporting pay, etc. etc. While many of these items might concern industrial engineers, (and if you have questions I'll try to answer them during the discussion period following my address), there are a number of issues with which industrial engineers are directly concerned, namely:

1. Job Evaluation
   and
2. Incentive Plans

and, occasionally, safety, hours of work, merit rating, job transfers, and bonuses other than incentive.

While I have listed only two issues out of the many listed above that come before arbitrators as being of direct concern to industrial engineers, it should be pointed out that these two occur more ofter than other issues. In this same recent survey by the American Arbitration Association, of 1728 issues heard, 330 or 19% were job evaluation and incentive grievances, and if we include the other items with which you might occasionally be concerned, the percentage goes up to almost 25%.

Now these are facts, and yet I'd be willing to wager that not 25% of you have ever sat in on an arbitration hearing, concerning job evaluation and incentives, nor been asked to testify at an arbitration hearing. I also would be willing to bet that less than half of you have ever been asked to prepare material to be used for arbitration of job evaluation or incentive grievances.

It occurs to me that there may be some persons in the audience today who cannot understand why job evaluation or incentives could cause a grievance that would come before an arbitrator. If there are such persons then they are going through life under the misapprehension that industrial engineering is an exact science. I hope that it comes as no surprise or as a shock to any of you, if I say that industrial engineering is unlike such engineering fields as mechanical, electrical, civil, etc., because we are not able always to measure accurately and without a shadow of doubt the interaction of many of the elements with which we deal. This is especially true with one particular element with which we deal the most. This element has as one of its scientific names—"homo sapiens"—namely us, you, me, the boss, the shop steward, the employee; sometimes one, sometimes the other. Engineers in other fields have many differences of opinion as to how the elements about which they know a great deal will react, so it is not surprising that we who apply the scientific approach to such an unknown, unmeasurable and volatile element as "homo sapiens". should have difficulty in agreeing on most anything concerning this element. We are, despite the fact that we deal with this unknown element, seeking a goal, and that is the efficient and economic operation of an enterprise, and in order to accomplish our ends, we apply the scientific approach. This scientific approach in its application tries to measure work pace, or how long it takes an average man to do a job, or measure the skill, the effort, the hazards, etc. that are in a job, but, as I'm sure you've all found out, these are difficult to measure, and differences of opinion occur. Where there are differences of opinion there can be disputes, and disputes lead to grievances, and in labor relations grievances often lead to arbitration.

Job Evaluation disputes (so-called) are very often disguised requests for individual wage increases or adjustments of incentive rates. However, what I intend to discuss and what I mean as job evaluation disputes that would usually concern industrial engineers are those grievances relating to the ranking of jobs within a more or less formal system or to the relationship between one job and another.

Usually these cases involve requests by the union for re-evaluation of certain factors such as "Education", "Responsibility for Materials and Equipment", "Experience", etc. These requests for reconsideration can be based on a number of things. Sometimes errors in the original evaluation are alleged, but more often the dispute is due to changes that have occurred in the job by changes in materials, product design, methods, etc. Then there are the cases that concern the question "should the work now being done by Jones, who is a laborer, be performed by a laborer or by a carpenter."

Typical of this are such grievances, and I quote some of the grievance statements that have been presented to me:

(a) "My job description of Milling Machine and Shaper Operator is obsolete in that it no longer describes the required duties. I request that the description be rewritten and evaluated."

or

(b) "The job write-up on the North Dock Shipper states that we have good working conditions and this couldn't be further from the truth, as we have all the conditions that prevail on an outside job."

or

(c) "My job description and work has materially changed since original classification as tolerances are closer and larger work has been put on this job."

or

(d) "The employees in the clean up gang (Spray Booth Cleaner) have been requested by the foremen to use wrenches. We maintain that all the wrench work done by the gang should be done by the men classed as Repairman-Small Shop Equipment."

(e) Then there was one where the union challenged the figure of $1000 as the probable damage to a machine that might be caused by work errors. The union claimed that the figure should be higher thus seeking to increase the point value and thereby putting the job into the next higher labor grade.

Now these are just a very few of the job evaluation grievances that I've had to decide, but they are quite typical.

Turning to the second category of cases with which industrial engineers are concerned, namely incentive grievances, I would like to call to your attention that most of these grievances come about when either the company or the union has sought to modify rates which, it was alleged, were either too "loose" or too "tight." I've also run into many cases where the question was raised as to whether management had the right to re-time jobs unilaterally and set new rates, subject to later grievances, or whether once having been set, rates could be changed only by negotiation. Most collective bargaining agreements contain some provision for changes in incentive rates where alterations occur in methods of production. The following are typical:

(a) Whether the changes that occurred in production methods were sufficient to justify changes in rates, and if so, could the rate for an entire job be re-evaluated or were permissible changes limited only to the elements of the job that had undergone a change.

(b) "Downtime" is another type of case that creates difficulty, especially when employees on incentive could not maintain their regular production because of machine breakdown or for other conditions beyond their control are paid for the "downtime" on the basis of average incentive earnings, rather than at base rate. This often creates questions of fact, and these facts then are presented and I've had to determine whether the employee couldn't earn incentive rates because of machine breakdown, etc., or whether he was deliberately slowing down as was claimed by the company.

(c) Still another question that I've had to decide was whether an incentive rated employee was entitled to his average earnings rather than base rates when transferred from an incentive job to an hourly rated job for the convenience of the company, and would it make any difference if he were transferred for his own convenience such as to avoid a lay-off?

(d) Then there's the whole area of simply being called in to check the standards established by management on a new job which the union claims are too tight.

These are the kinds of cases that usually concern industrial engineers. Now the question is what can you do as industrial engineers to: one, prevent such questions as these getting to arbitration, and two, once they get there, win the case for your company or union. Oh yes, unions employ industrial engineers. They even employ industrial engineering consultants. I, for example, have worked for quite a few unions in the sense that they've employed me to check standards to obtain advice on new incentive or job evaluation procedures systems with which they were unfamiliar. In one case, for example, a union in a flour mill had me check into whether one man could operate three mixers where formerly he had operated one. The company, as a result of changes in methods, including increased mechanization, had notified the union that this change was contemplated. The local union president was besieged by the mixer operators who claimed it was impossible to operate three mixers in the manner the company was planning. Since the plan was still in the development stage no actual grievance could be filed. The union president decided he would hire his own industrial engineer to check the company's industrial engineers' claims. The company was agreeable and I was called in as a representative of the union.

This type of thing makes good sense to me and in my opinion indicates that some unions and their elected officials are practicising labor statesmanship. The company in this situation could, of course, have refused the union permission to bring in their own industrial engineer, but they had, for the most part, a good and intelligent relationship with the union and showed good statesmanship on their part by agreeing to the action.

Taking up the first part of the question, or what can you do to prevent grievances occuring concerning industrial engineering problems: The answer is relatively simple—not too much different than you probably are already doing or you know should be done. Of course, this latter is the problem, there are many things you know should be done, but you are not in a position to authorize the proper actions.

I am sure that every industrial engineer here tries to be as honest as he knows how when he establishes a standard, rates a time study or job for a job evaluation plan; yet the union representing your employees often seems to be questioning your honesty. Many literally believe you've "fudged" the figures so that the company that pays your salary will obtain some unfair or unearned monetary gain from the sweat of an employee. In the past 25 years, I've been on all sides of this picture—I've been a factory worker, a full time management employee, a consultant to management, a consultant to labor, and an arbitrator. As an arbitrator I've handled several hundred cases in the last few years, most of which have concerned production standards and job evaluation, and if there is any one thing that I've noticed during all these years and through the varied experiences which most often cause these kinds of grievances, it is management secrecy. Far too many managements take the attitude that industrial engineering data is sacrosanct company information. How the standards were obtained, the time study figures used to build up data, or the factors used to evaluate jobs, is, according to some companies, nobody's business but theirs and especially should be hidden from their employees and their representatives, the union. There are also a few companies that take the attitude that they are not really hiding anything; it's just that the union representatives don't understand these technical matters and might misinterpret the figures, and this would cause even more trouble. This sort of thing is, of course, just plain "poppycock" (whatever that word really means, and if this weren't a public meeting I could use somewhat stronger words).

I don't think any of you need a course in psychology to know that when some one hides information from you, you become suspicious of either the person's motives or in the accuracy of the information that is being withheld. Therefore, my advice to you, if you work for such a company, is to get them to make such information available to the union. Please now, if you quote me, and if you follow my advice, don't think that industrial engineering grievances will disappear immediately; remember what I am now going to say—the mere opening up of industrial engineering information will not necessarily eliminate immediately industrial engineering grievances—after all, a company by just this action alone will not eliminate the union's suspicions as to its motives. After all, the secrecy practiced by most companies is usually just one exemplification of its attitude toward its union and collective bargaining agreements; changing this one aspect does not indicate to even the most naive union representative a change in company attitude. Another way, perhaps, of explaining my meaning is to say that in most cases of labor-management situations with which I've been familiar, those companies who were open and above-board in all their dealings with their employees and their employees representatives—those companies that gave copies of their job evaluation plan or made available time studies, rating, or any other necessary data—have either had less grievances and arbitrations, or have found it easier to settle or win the grievances and arbitrations.

It should be quite obvious from what I've just said that there is no "pat" method of preventing grievances and arbitrations, any more than there is any way to prevent lawsuits or any other actions that occur due to differences in opinion or differences in interpretation of agreements.

Therefore, since even under the most amicable and agreeable contractual relationships, grievances will occur; and where there are grievances, there often are arbitrations; and where there are arbitrations involving job evaluation or incentives, there *should be* industrial engineers. Of course, this is not always the case. I've served as arbitrator in a number of cases involving job evaluation and incentives where the industrial engineer did not appear for either side, and neither side used industrial engineering material that I'm sure must have been available.

For the sake of avoiding a whole area that could be the subject of another speech, I'm going to skip over the grievance procedure until it has reached the stage when one party or the other has been notified that the grievance must go to arbitration. Once this stage has been reached, one of the first actions that must occur is the selection of an arbitrator. Even in this matter controversy occurs, and it is difficult to obtain agreement as to whether it is better to have an industrial engineer as an arbitrator of job evaluation and incentive grievances, a lawyer, or an educator with some knowledge of such matters.

Naturally some arbitrators who are not industrial engineers will and can find reasons why it is not necessary to have industrial engineers for arbitrators, or that it is even better not to do so. However, this is not my opinion, but then I, too, am perhaps prejudiced. It does, however, seem logical to me, and, I'm sure, it must seem logical to most of you in this audience that it would be best to have an industrial engineer umpire these technical cases. This is a reasonable position to take, because you feel that an industrial engineer will understand your language and methods.

There are two factors that govern the selection of an industrial engineer as the arbitrator:

In the first place, there are not too many industrial engineers who are arbitrators, and secondly, the union is not always willing to accept an industrial engineer as an arbitrator.

Parenthetically, one is probably caused by the other.

At any event, there are not too many industrial engineers who enjoy acceptability with unions. This is not because the available industrial engineers are dishonest, but rather because most of them are employed or are retained by management, and rightly or wrongly, are considered as employer oriented.

I would like also to point out to you that the mere fact that a man is an industrial engineer does not necessarily guarantee that he knows how to carry out the rather complex duties of an arbitrator, which still must be followed no matter what kind of a grievance is involved. Actually you might be better off to use an experienced arbitrator whether he be a lawyer or educator, than an inexperienced arbitrator who is an industrial engineer. By "experienced" I mean a man who has had substantial experience handling arbitrations concerning job evaluation and incentives. If you can't obtain such a person then see that your collective bargaining agreement provides or that you gain agreement for the arbitrator to obtain technical assistance from an industrial engineer of his choice.

Assuming now that you've agreed with the union on an arbitrator, your next step is to prepare your case properly, and to some extent the kind of preparation will depend on whether the arbitrator agreed upon is an industrial engineer or not. But whatever he is, there is no substitute for a well prepared case with documented material.

It has been my sad experience, and often a resulting sad experience to a company, to find you industrial engineers called in almost as an afterthought and put on the witness stand by the Industrial Relations Director, Labor Coordinator, or "downtown" lawyer, who will proceed to ask you to testify that the standards or ratings are correct and that every scientific procedure known to man since Aristotle has been used to assure that the figures and facts used by the company are accurate, fair and incontrovertible. Now, maybe you'll fool some inexperienced arbitrator-lawyer or arbitrator-economist on his first case with that kind of testimony, but you'll never get anywhere with an experienced man, nor will a properly represented union let you get away with such a defense.

There is only one way to defend what you've done, and that's with the facts, honestly obtained and honestly and clearly presented, without a lot of industrial engineering jargon and gobble-de-gook. This matter of using every day English is, of course, especially important if your arbitrator is not an industrial engineer. Even if he is an industrial engineer, you're better off using every day terms; for my part, I'm unimpressed by the industrial engineers or company representatives who spend all their time in a hearing trying to show the arbitrator how much more they know than those poor uninformed union representatives. Your job is to make the arbitrator understand, without being condescending or self-righteous toward him or the union. Your job, and you better get it across to the Industrial Relations Department that it is your job, is to gather the necessary technical material and all the substantiating information necessary and put it together in a presentable and understandable package. No one can do it better than trained industrial engineers. This does not mean that you shouldn't consult and work with the industrial relations people. After all, they have training and experience that will be helpful.

In closing, I think I should mention that even if you follow all the advice I've given, that even if all your information and facts are absolutely correct, the arbitrator may still rule against you. In your eyes, if he does, it's obviously a mistake, or he's an idiot. Maybe he did make a mistake, or maybe you didn't give him all the facts so that he understood them, or maybe even you're the idiot. Whatever the reason you lost, there's no need to cut your throat or quit your job, or even to decapitate the arbitrator. Just remember the arbitrator has done everything in his power and to the best of his knowledge, with the information available, to give a fair decision within the provision of the collective bargaining agreement.

It is even quite possible that the arbitrator's decision may leave the beautiful well-balanced symmetrical system of your wage and job structure slightly askew; your incentive plan may have had some standards loosened or job evaluation factor incorrectly applied. This is, of course, regrettable. It's happened to me, and I've been plenty annoyed; and, I'm sure, decisions I've made have been annoying to other industrial engineers. But, as I've said earlier in this paper, industrial engineering at best is only a highly reliable and informed way of reaching decisions and cannot be compared with the physical sciences in its revelation of truth. Add to this that arbitration is also, perhaps in a less technical sense, an informed way of reaching a valued decision, and you will realize that the failure of an arbitrator to agree with you is possible, and that it will not destroy your company nor will it reduce your standing and usefulness to your company or union. Just remember that perhaps the arbitrator didn't understand what you were saying—to paraphrase the old J I T maxim—"if the arbitrator hasn't understood, the engineer hasn't made himself clear." Maybe in the next case you'll be able to do a better job of explaining what it was all about.

THE MANAGERIAL PROBLEMS OF INDUSTRY AND THEIR INDUSTRIAL ENGINEERING IMPLICATIONS

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THE MANAGERIAL PROBLEMS OF INDUSTRY AND THEIR INDUSTRIAL ENGINEERING IMPLICATION

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THERE have been numerous studies conducted pertaining to the causes of industrial failure. Most of the surveys made reach the same conclusion: namely, that the most important cause of industrial failure is "inadequate managerial skill".

This paper is intended to answer three relevant questions pertaining to this conclusion:

1. What is meant by managerial skill?

2. In what specific areas does management fail?

3. What can the Industrial Engineering profession do to alleviate these problems?

MANAGERIAL SKILL

Industry and business have become larger and more complex during the last half century; we have recognized the need for the development of techniques of science to replace guesses, estimates and appearances. Walter Rautenstrauch has defined scientific method in part as follows: " . . . Scientific method is used when judgment is based on measurement and not on guesses, rumors, beliefs. It is the method by which the 'facts in the case' are weighed. Since science is based on measurement, any situation which can be treated by the use of units, methods and means of measurement has reached its highest possibility of development in the matter of scientific treatment."

The challenge of effective management naturally increases as business size increases. Thus as business methods and products become more complex and relationships with other businesses, consumers, the union and the government more intricate, the need for skilled management expands materially.

How well does industry measure? How well does it control? organize? apply scientific method? Where, why and in what specific areas does industry fail?

THE PROBLEMS OF INDUSTRY

We have concluded after much study and analysis that the three major problems of industry in their respective order are:

1. Organization and the inability of management to properly delegate and control authority and responsibility.

2. The lack of utilization of scientific management tools to provide the necessary data for management decision making.

3. Lack of managerial action in the more important problems of management.

Let us examine each of these problems.

Organization, or the lack of the proper functioning of the organization, is the single most important problem of industry. The problem of organization takes form primarily through the lack of definition and delegation of authority and responsibility. The key to effective organization is the delegation of authority. Without delegation, organization does not exist for there would remain only a one-man company.

A survey made by the writers a few years ago indicated that out of forty companies surveyed, eighty-five per cent reported organizational difficulties.

The major factors attributing to ineffective organizational structure are:

—over dependence of the organization upon those who hold too much power,

—excessive burdens upon executives who enmesh themselves in routine trivia,

—the blockading of subordinate development and their dissatisfaction with the organization and company.

—the overlapping of function and responsibility and authority.

Organizational difficulties appeared to have stemmed from the fact that nearly all companies have grown from very small organizations where the delegating of authority was non-existent. As the company grows and more people are needed to perform the various functions, delegation of authority becomes a major problem. The difficulty has been failure to recognize that there has been an organizational change that initially creates the problem; and top management's inability to revise their functions, and the functions of subordinates as the company grows, that magnifies the problem.

Numerous sub problems, such as poor morale, poor cooperative spirit among middle-management employees and lack of advancement opportunities can be directly attributed to the poor structure of the organization.

LACK OF SCIENTIFIC MANAGEMENT TECHNIQUE

I think it can be safely stated that the greater majority of firms are not using techniques of standard costs, sales analysis and standards, time study incentives, methods engineering or what we know as Industrial Engineering.

Specifically, industry is particularly weak in the area of costing and pricing. Costs of many different products and operations are lumped together so that analysis is difficult if not impossible.

Prices are based on faulty and obsolete formulas.

There is insufficient, improper and incorrect use of the break-even chart and profit and loss chart. In short, it can safely be said that industry is not taking full advantage of Industrial Engineering technique in its fullest extent.

THE PROBLEM OF MANAGERIAL ACTION

The third major problem, lack of managerial action, is, of course, a direct outgrowth of problems one and two. The poor organization structure and lack of scientific data makes it impossible to take necessary action on specific problems at the right time.

THE INDUSTRIAL ENGINEERING IMPLICATION

I would like to pose two questions regarding the Industrial Engineering responsibility to industry:

1. Is the Industrial Engineering profession solving the major problems of management?

2. What techniques are necessary for the industrial Engineering profession to develop or expand upon in order to provide better service to industry?

Are we, the Industrial Engineers, solving the problems of management? I think it can be stated that the Industrial Engineering contribution to plant and office efficiency has been outstanding.

What about our contribution to the field of organization? pricing? sales analysis? profit control?

In the field of organization I do not feel that we are doing as much work as we should. Industry's major problem concerns itself with management's unawareness that the organization structure is inefficient and ineffectual. It is this inability of recognition that impedes progress in this field.

The questioning procedure that has been so successful in methods engineering should be used to a greater extent in the study of organization. I shall list several appropriate questions:

1. Is responsibility of function coupled with the authority?

2. Do the lines for responsibility and authority cross each other?

3. Are the important functions of the organization being neglected?

4. Are the secondary functions being overstressed?

5. Are there duplications of function?

6. Are executives unnecessarily burdened?

7. Are subordinate executives being suppressed?

8. Are the personnel of each function in accord with the duties of the position?

9. Are specialists handling functions out of their line?

10. Is the same executive handling several unrelated functions?

Once the problem of organization is recognized and brought into the open, it is relatively easy to match up the important functions with the adept personnel for that function. The organization must provide for lines of authority and responsibility that leave no gaps and do not cross each other. All responsibilities must be assigned, but no two men should be assigned the same function.

Top management function is a coordinating duty rather than a mechanical function. As a rule, the coordinating function is largely a question of human relations rather than a technical or mechanical matter. The majority of managements we have come into contact with fail in that respect; hence, the cause of the organization problems.

In many companies foremen perform mechanical and repair functions, top management performs staff functions and middle management is trying to fill the gaps.

In order to advance, industry must be cognizant of such situations and take the necessary reorganization steps immediately as the need arises. It is the Industrial Engineering function to make top management aware of inefficiency of the organization structure.

PROFIT CONTROL

In the field of profit analysis the Industrial Engineering profession is not doing as much work as we should.

I point in this field to the work popularized by Professors Rautenstrauch and Villers in their many writings.

I think the first step in any Industrial Engineering problem is the calculation of the profit structure. By profit structure is meant the amount of profit or loss that can be expected for any period prior to the start of that period.

The profit structure is calculated by the following formula:

Total Expense equals Y equals a plus bx
a equals fixed costs or costs that do not vary with sales
b equals ratio of total variable expenses to sales
x equals sales

By adding the fixed and variable costs together in that ratio we can derive the total cost for any sales volume or the profit at various sales volumes.

The importance of the profit structure is that it enables management to know what its profit picture will be before the period begins. Furthermore, and even more importantly, it enables management to take action upon its profit structure in order to convert undesirable operations to more desirable ones.

It is possible to subdivide the profit structure into any number of divisions, i. e., departments, branches, products, line of products, etc. It becomes easy to establish standard costs from the profit structure analysis and from it compare the actual costs as the period progresses.

PRICING

We, as a profession, are doing very little in the pricing field.

A recent National Industrial Conference Board Survey revealed that less than three per cent of 155 companies taking part in the survey follow clear cut procedures in setting prices. Of course, many companies that use formalized pricing procedures use faulty and obsolete formulas

Most companies that we have come into contact with use the following procedure or one similar to it.

They add the following costs:

1. Labor	$10.00	
2. Materials	5.00	
3. Selling (figured at 10% of material labor)	1.50	
4. Overhead or Burden (figured at 200% Material & Labor)	30.00	
5. Total Cost		$46.50
6. Profit (add 25%)		11.63
7. Selling Price		$58.13

The major problem concerned with pricing is the computing of the overhead burden costs to the product. Most companies, as shown above, express the overhead figure as a percentage of material and labor. It can be clearly shown that the overhead cost does not vary in direct relationship to material and labor.

Overhead fixed costs vary only in relation to sales as can be shown below.

Assuming a fixed cost of $3,000.00 per month, the ratio of fixed costs to sales will be as follows for varying sales volumes.

SALES	FIXED COST	RATIO FIXED COST-SALES
$ 5,000	$3,000	60
8,000	3,000	37
11,000	3,000	27
14,000	3,000	21.4

Fixed costs are costs incurred in operating the business, not a cost in producing the product.

The correct pricing procedure must eminate from the desirable profit structure. Each item or products price must conform to the overall profit structure. Only by pricing through estimated variable costs as a percentage of sales can this be accomplished.

SALES ANALYSIS AND STANDARDS

The area sales analysis and sales standards can be a most fruitful one for Industrial Engineers.

Once we have established an optimum profit point from the profit structure, we can select a feasible sales point to become the sales standard. The sales department can then be organized to reach that point.

Sales standards can be established along the same basis for each salesman and on a monthly basis.

In companies where we have applied sales standards, the results have been particularly gratifying. Most companies use last year's sales as a standard, rather than the more optimum point as shown by the profit structure.

SUMMARY

I have discussed the problems of management and it can be stated that the three most important confronting industry today are:

1. Management organization
2. Management technique, and
3. Managerial action

As Industrial Engineers we must increase our services and techniques in the fields of organization analysis, profit control, pricing analyis and sales methods and standards.

IMPROVED GOVERNMENT THROUGH INDUSTRIAL ENGINEERING

by L. R. BECHT

U. S. NAVAL AIR STATION, NORTH ISLAND

L. R. Becht, Production Engineering Superintendent at the Naval Air Station, North Island, San Diego has been president of various engineering, civic and business organizations. Last year, under his leadership, the San Diego Chapter of the AIIE was named the Outstanding AIIE Chapter for 1959. He is a graduate registered professional industrial engineer, member of various engineering and professional societies, and is listed in the 1959 Who's Who in Engineering. His background includes some twenty-five years of progressive practical experience in the field of Industrial Engineering, mainly in the areas of work measurement, facilities planning, organization planning, and product engineering. He is an accomplished speaker and has participated in a large number of engineering seminars.

IMPROVED GOVERNMENT THROUGH INDUSTRIAL ENGINEERING

by LAWRENCE R. BECHT*

Production Eng. Supt., NAS, North Is.

DURING this session of the conference, we shall explore a special area of industrial engineering that, in sheer magnitude of size and scope, far surpasses any problem areas that most of you have ever been asked to deal with. We shall also pose one of the greatest management challenges in the world—which YOU, as industrial engineers, more than anyone else, should be able to handle.

In addition, we will examine the vast parameters of governmental operations—analyze that nebulous individual known as the government employee—show what has been accomplished in public service to date through industrial engineering—outline what the industrial engineering profession can do in the future for government—and, if time permits, we'll try to answer a few questions that, it is hoped, this discussion may generate. This may get a little stormy in spots but, as Charles Kettering so aptly put it, 'no one would ever have crossed the ocean if he could have gotten off the ship in the storm'.

1. *THE GOVERNMENT EMPLOYEE*—You see standing before you a perfect specimen—a specimen of that purportedly disreputable group of egg-headed characters known as bureaucrats. Yes, I am a government employee—and, I might add, I'm very proud of it. But it is time that we receive intelligent, courageous, knowledgeable help—from you—and you—all of you—to dispel the flossy cloak of disrespectability that seems to surround those of us who have chosen to serve the government.

There appears to be a sort of oscillating confusion about government employment—at the Federal, State, and Local levels. And there is a disturbing extrapolation or connotation on the omnibus term bureaucrat—in the category of a dirty word—with poorly veiled undertones in the direction of pampered and coddled sedentary neophytes.

As an opening gambit, let me give you a prime example of what I mean. A friend of mine, an executive in a local industrial plant in a joking vein gave me this little gem—I assume that it was composed by one of his subordinates (on company time, of course)—in any event it goes like this . . . Now I know that this was just meant to be humorous, good for a few sophisticated laughs, I suppose—but, despite my thick skin, I'm getting just a little sensitive to this incestuous inbreeding. You see, I *know* from personal exposure that this is a completely erroneous portrayal—and, incidentally, I have spent many more years in private industry than in government—and this time was spent with three of the largest corporations in the United States. I *know* that the average government employee is a hardworking, dedicated, loyal, and competent worker. Let there be no misunderstanding on this point.

The scope and magnitude of government operations almost defies the imagination—as you will see in a few moments: The thousands, yes millions, of government people backing these operations are not standing still—and they are *not* playing dead by any stretch of the imagination. They are driving forward with a realistic evaluation of practical needs—based on a sound credo of economic justification. No apology is needed, and none is being made—these are employees of the highest calibre. Permit me to read a quote or two that bears on this item: The American Assembly, a nonpartisan program conducted by Columbia University, has this to say:

> "Our observations have demonstrated that Federal employees of all ranks are, by and large, as competent, loyal, and devoted as employees found in private enterprise. The *maximum* efficiency of these employees, however, will never be achieved without a fundamental change in the attitudes toward public employees on the part of the American citizenry *and their leaders*. As a people, we can no longer afford the luxury of uninformed and unreasoning deprecation of public employees. Deep-seated and long-standing biases and misconceptions must be rooted out of the American folklore relative to Government and public employment."

Many leading citizens have also become concerned with the need for better public understanding and have spoken out strongly in behalf of the career employee. These are successful business men who have come into government to serve temporarily in important positions. Typical is the comment of Clarence Randall, Chairman of the Board of Inland Steel and former Head of the Commission on Foreign Economic Policy who stated in LIFE Magazine:

> "As the days passed into weeks and the weeks into months, I found growing in my mind a new respect, and in my heart a warm affection, for many career men. I came to know them well, and comparing them with men of like age in business, I rated them high. I found at every level in government individuals whose unselfish dedication to the services of the United States was an inspiration."

Mr. James C. Worthy who left Sears, Roebuck and Company to become Assistant Secretary of Commerce declared:

> "The businessman coming into Government is likely to find a great many able people in the career service, people he would very much like to have in his own business; and whom, if they were in his own business, he would *be willing to pay far more than they are earning now*. I hope that as I go back to private life, I will be able to help correct some of the mistaken impressions which prevail in certain quarters about the kind of people who work for the government. I can say in all sincerity that for hard work and patient de-

votion it would be hard to find their equal in any line of endeavor."

Just one more, H. Lee White, former Assistant Secretary for the Air Force, as he returned to his private law practice stated:

"I have been much impressed by the quality and character of those Civil Service employees with whom I came in daily contact in the Air Force. It is my belief that, on the average, a Civil Service employee has equal if not greater ability than his opposite numbers in private industry. It is too bad that the ordinary citizen in the United States does not realize how much he owes to those people who have given up the opportunity to make a great deal of money in order to work in the most important work of all—for the government."

There are many, many more just like these—unsolicited and publicly stated on the record. Accordingly, as an incidental but pertinent part of this session's presentation, in all humble sincerity, I earnestly invite your intelligent and professional cooperation in bringing to the general public a fuller appreciation and a better understanding of the unselfish dedication of the government employee. I appreciate that this matter of winning public recognition is much more involved than just asking for it. It is unfortunate that publicity and recognition are not logical phenomena. We are not particularly concerned about publicity—we are tremendously interested in your constructive recognition.

2. *SCOPE OF GOVERNMENT OPERATIONS*—Now, let's examine the scope and magnitude of governmental operations. At the present time there are about 71,000,000 workers in the total U. S. civilian labor force. Of this total, there are 7,800,000 that are employed by the government as follows: 2,200,000 work for the Federal Government and 5,600,000 work for State and Local governments. I'm not going to bore you with a host of statistical detail, but I did want to give you a brief glimpse of the parameters that we are discussing. If you are truly interested in a detailed breakdown of the national labor force you may easily obtain such from the Bureau of Labor Statistics of the Department of Labor. However, mere numbers are never enough—they require intelligent interpretation.

Some of you may feel that a ratio of one government worker to every nine of the total labor force is a bit lopsided. I've even heard some—people remark that it's outrageous. But just pause for a brief moment —and *think*. Let me enumerate just a few of the many services that you and I receive—such as: fire protection, law enforcement—including all of the courts, education (2,400,000 alone), agriculture and forestry, national defense, tax collectors, printing of money, highways and waterways, legislative bodies, social security, postal service, public utilities, and the list goes on almost ad infinitum. These are services that YOU asked for—that YOU approved. So, obviously, YOU must be responsible for the cost *and* the management of these services. Remember, if there are problem areas in government, we should try to fix the trouble—not just fix the blame. The search should be for the area and how to correct it—not for a scapegoat upon which to pin the blame.

Let's look at one of these services, albeit one of the larger ones, the Post Office Department. There are some 540,000 postal employees working out of about 36,000 post offices of all classes. Last year this Department processed 61 *billion* pieces of mail, weighing over 11 billion pounds. Based on an average of ten handlings for each piece of mail, this represents 610 billion piece handlings per year. It is reliably estimated that in the next 20 years this figure will almost double —reaching 110 billion pieces annually. Staggering? Big business?—The biggest! Please note that here you have one of the cheapest, yet most utilitarian services that we are fortunate to receive—and still there are some individuals who bitterly oppose even a one-cent increase in postal rates. This may give you a quick feel for the kind of ball park we are in.

3. *I-E ACCOMPLISHMENTS TO DATE*—Now, there have been many, many noteworthy industrial engineering accomplishments during the past few years within government agencies. The concept of industrial engineering as applied to public services operations is still somewhat new—but it has a very promising start —and, with the help of properly qualified professional personnel, it will practically revamp many phases of public administration—particularly if it is based on practical rationalization rather than managerial leapfrogging.

I am going to by-pass Local and State government bodies—for two very good reasons, namely (1) to date, on most instances, they have done very little, practically nothing, to encourage the utilization of sound industrial engineering techniques and (2) speaking quite frankly, they are generally clobbered with local or partisan politics that would stifle any constructive improvement programs—and there is nothing more distressing than the insatiable hunger of constituent interests. Of course, there are some exceptions—like Dallas and Fort Worth, that have fine outstanding local governments. Peculiarly enough, City, County, and State administrative officials generally are paid much higher salaries than Federal personnel holding equal or, in many cases, much more responsible positions.

Accordingly, I'll direct my remarks primarily at Federal government agencies, and particularly at Department of Defense Departments with which I am most familiar. Prior to 1940, there was a congressional statutory prohibition against time and motion studies in government areas. As you might suspect, this had a very salutory curtailing effect with respect to any substantial management improvement programs. However, since about 1945, the growth and acceleration of industrial engineering applications within the Federal Government have been rapid and widespread; not all that we may have wished for, but certainly most encouraging.

The Post Office Department—as a case in point, is beginning to reflect this management improvement trend under the extremely capable leadership of Wade S. Plummer, Director of Research and Engineering. In 1952, just seven years ago, there were only ten people in their centralized engineering group—it has now expanded to 125 plus more than 150 on a consultant basis. And there are now 15 geographical Regional Offices, each headed by a Regional Operations Director, with a staff of five to ten engineers. In 1957, the Work Performance Standards System was installed and now 78% of the direct man hours are covered by direct standards. During a recent four-week accounting period, the actual man hours reported under the system exceeded 13,000,000 man hours. It is expected that the standards coverage soon will apply to approximately 200 million man hours on an annual basis. This is truly realistic progress—and completely free from any man-made industrial cheese-cake. Remember now, the processing of mail is not (as many believe) a routine affair. The mailing public deposits its mail in various receptacles and stations throughout the city at all hours during the day with the heaviest concentration usually between four and seven P. M. It is necessary to collect and process this mail in a very short time so that it may be dispatched advantageously on common carriers. Conversely, mail arriving from other cities to be delivered locally vary in volume and time of receipt throughout the nation. All of this calls for a flexibility and coordination of the highest degree.

Facilities planning is another major study area in the Post Office Department. The principal method at the present time for obtaining new facilities is the commercial leasing program. Private capital is investing an average of more than $5,000,000 a month in new postal buildings. Despite these current improvements in facility developments, it is readily apparent that the great growth of mail volume can only be met by a complete rehabilitation of the physical plant. It is estimated that this program will require an expenditure of about $2 billion of which $1.5 billion would be invested by private capital. And don't forget that postal operations vary from a one-man operation in a cross-roads store to the hugh centralized operation of 18,000 employees in Chicago and the contrasting decentralized operations of New York City which employs 35,000 people.

As a Chief Industrial Engineer, how would you like to get up *each* morning with the soul-wrenching knowledge that at the end of that particular day, your department would have operated at a loss of $2 million? Yet, despite all of the truly commendable efforts of the postal administration, this happens every day to the Post Office Department. God willing, with continued dedicated efforts—and a slight increase in postage (say one cent) this enigma will be resolved. What a challenge this is to industrial engineering!

Let's take a quick look at the Department of Defense. The Army has been very progressive in the industrial engineering field—utilizing some 3,000 management engineers on a large variety of management improvement programs. Significantly enough, all but 144 of these engineers are being paid *less* than the average industry rate for professional non-supervisory industrial engineers—and yet they contend with an annual budget of $10 billion! Last year, in work simplification alone, a savings of over $7 million was realized for a return of 19 to 1 on each dollar invested. They have developed excellent manuals on Motion Economy, Flow Process Charting, and Management Improvement. The annual management improvement reports from the various Army technical services and commands are extremely well done. Here are a few reported outstanding examples: The Corps of Engineers implemented 2,329 improvement projects last year resulting in savings of $23,000,000; Army Headquarters—$1,906,000; the Third Army at Fort McPherson, Georgia, 107 projects during the last half of the Fiscal Year 1959 with an annual savings of $692,000; and so the record goes—from large projects showing savings of hundreds of thousands to small but nonetheless equally important items of a few thousand —all contributing significantly to a more economical military operation, a more effective soldier and a stronger U. S. Army. No doubt about it—the Army is doing a fine job.

The Air Force is also rapidly coming to the fore in the management improvement area. Being still a somewhat young organization, it has not yet had a full opportunity to flex its muscles in the industrial engineering field—but it is quickly getting there. Here are three manuals put out by the Air Force on Work Measurement, Work Simplification, and Management Engineering Project Administration. I will be quite frank to say that for completeness, sound approach, and clear definition, I personally have not seen anything in private industry that is any better—or, for that matter, will even match these fine Air Force management-type publications.

You might properly assume, and rightfully so, that I could also expound for several hours on the Navy's fine industrial engineering achievements—all, of course, in a complimentary vein. The Navy *has* made tremendous gains in this area—particularly in work measurement, mechanized production control, value engineering, and paperwork management. The former Bureau of Ordnance (now combined with the Bureau of Aeronautics to form the Bureau of Naval Weapons) has been a consistent leader in Naval industrial engineering techniques. The Navy Management Office has also been doing an outstanding job towards stimulating and guiding Navy efforts in this field. There are many instances where Navy industrial engineers have been instrumental in achieving substantial savings in operational functions. Industrial engineering is now becoming one of the most potent management tools in the Navy system. However, there have been roadblocks—and (quoting from the December Navy Management Review) they are worth noting. "The biggest has been the lack of complete understanding on the part of the manager. Some managers simply do not know what industrial engineering attempts to accomplish. They do not effectively use the data which production or cost control programs furnish them. Since proper use of data is the key to any positive results, *management's failure in this area is the major impediment to complete success.* A second problem in industrial engineering efforts has been lack of funds for redesigning older facilities and installing modern material handling equipment and new processing techniques. Program stability has also been a problem. It generally takes a few years before industrial engineering techniques can be fully applied and before positive results are shown. A turnover in personnel during this period may bring in persons who have no understanding of a program that started several years before they came to the activity. As a result, they may fail to give it the needed support. Nevertheless, despite these roadblocks, any objective analysis of industrial engineering in the Navy would have to judge the program as a solid success." There is a commendable realization here that efficient management cannot be achieved by the mere expedient of waving a magic wand sparked with such sonorous phrases as automation, data processing, numerical control, brainstorming, or what have you. These are admittedly useful techniques—but they are dangerous and costly in the hands of the uninitiated.

One final comment on accomplishments, since December 1954 the Federal Government has saved $558 million as a result of its employee suggestion program. It has paid out $40 million in cash to alert employees, or about $1 for every $18 saved. 1959 was the fifth consecutive year in which *new* records were made in the number of economy suggestions that were submitted and adopted.

While a good many people plunge ahead on space-happy excursions, someone has to tend the store and get out the day-to-day functional hardware. We, in government, have to guard against overdoing the power of positive thinking by maintaining the proper concept of balance. This requires recognition of the basic principles that with mass goes weight, that quality is accompanied by cost—and that specialization breeds inflexibility. In simple terms this means that 'government for the people' is a 24-hour, 365-day, year-after-year responsibility. Suffice to say that it is getting done (bureaucrats notwithstanding) with obvious increasing effectiveness. The record itself will attest to this.

4. *POTENTIAL I-E AREAS*—As you can readily see, there are many government areas that lend themselves to industrial engineering techniques. Although the Federal Government is the largest single employer in the nation, these techniques can apply equally well to Local and State organizations. Industrial plants, supply and public works centers, transportation systems, huge clerical units, personnel handling, research centers, and general administrative offices—all of these are fertile areas for industrial engineering—almost begging for attention.

From a functional standpoint, work measurement—particularly utilizing work sampling—probably leads the way, followed closely by work simplification, methods improvement, facilities planning, organization planning, cost reduction, paperwork management, budgetary analysis, management surveys, production control—well, you name it, and I'll guarantee *we need it.* Actually, the Federal Government is making commendable headway (though not enough) in most of these functional areas. Local and State government departments offer the greatest potential since this is almost virgin territory from an industrial engineering standpoint. Public administration, at the Local and State level, for some strange reason has steered shy of industrial engineering—preferring to fall back on people with business administration degrees or backgrounds. I am firmly convinced that many local department heads actually fear improvement programs and dread loss of personnel (which they relate to status). In these latter instances, I must confess that I bow to the implacable reality of Parkinson's Law.

If we are truly—and I repeat TRULY—interested in improving government operations, in reducing government costs—*and taxes,* then we don't have to resort to any other approach than the tried and true field of industrial engineering. It is as simple as that. Nothing complicated, no blue sky sophistication, no romantic or dreamy exotic spellbinding formulas—just plain old work measurement, organization planning, methods analysis, et cetera. Sound new? Of course not.

5. *PRO's AND CON's FACING I-E IN GOVERNMENT*—Perhaps we should inspect some of the advantages and disadvantages that relate to the industrial engineers in government. On the negative side are such items as low pay (by far the saddest factor), the wearisome red tape and historical archaicness of civil service procedures, severe recruitment and job qualification limitations, extremely slow personal advancement due to congressional restrictions, the frustration of tardy improvement implementations, the lack of facility funds (mostly Federal), the lack of appropriate personal recognition or prestige (except for elective officials) and, finally, the extreme difficulty encountered in removing unsatisfactory employees. There have been innumerable surveys, Hoover Commission Reports and similar studies—all designed to produce constructive end results; but positive personnel improvements have been very slow in developing. The Armed Forces Management publication just last December bluntly stated in an editorial, "In our free enterprise system, the easiest way to pull top people into government is to pay them enough to make it worth their while. Instead we try to rely on devotion to cause and country." Some day, it is hoped that a righteous ground swell of public opinion will insist on remedial therapy in this area.

There is, of course, a plus side to the ledger—and it has some strong arguments. There is an excellent retirement plan, complemented by equitable insurance, vacation and sick leave provisions. There is solid job protection (security) against personal bias—and incidentally, I've seen the unfortunate converse of this in some private industrial firms. Because of existing recruiting difficulties, and the consequent internal sparsity of rugged competition, really good people have a prompt entre' to attractive promotional openings as they occur. Finally, but perhaps most significant, here is a real opportunity for a life-time of truly dedicated public service. Service that you can be justly proud of —in behalf of this great country of ours. A shining example of such dedication, I'm sure you will all agree, is exemplified by J. Edgar Hoover, the hardworking, capable and loyal Director of the Federal Bureau of Investigation.

I'll not corrupt the word 'loyalty' as a means to cover defections in civil service practices. I believe it was E. F. Tangeman who stated that "loyalty is a very important idea in an organization; it is essential to morale and even to survival. But the concept must be thought-linked, not emotion-linked. Every time loyalty is a criterion, these questions must be asked: Is this just an easy 'out'? A subtitute for thought, action, or facing facts? A way to cover up bungling? A virtuous-sounding echo to a quietly passed buck? A synonym for something-for-nothing? I sincerely hope that the unquestioned loyalty of Federal government employees is not being subjected to such pious maneuvering.

6. *THE CHALLENGE*—The closing of the past decade, the 'fifties has seen some momentous changes in research, technocracy, and industrial developments. Concepts that were new or unknown at the beginning of the decade are now thoroughly accepted without question. The 'sixties will bring even more startling innovations. Explorations of the universe, other planets, the interior of the earth, the floor of the ocean—all of these hard-to-believe accomplishments and their accompanying gadgetry stagger our imagination. But I doubt if there is one person in this room today that seriously questions the feasibility of these things.

It is hoped that, during the 'sixties, equally startling improvements will take place in the area of government operations. Sporadic efforts are being made to de-emphasize the superficial and re-emphasize the essential. But opinion on essentiality is worse than divided; it is confused and too often based on tax bills, personal offspring, or prejudice rather than the 'greatest good for the greatest number'. Edward Young, more than two centuries ago, wrote "Procrastination is the thief of time." It steals more than that; it also steals our self-respect, our fun, even complete realization of our ambition. This, then, is the challenge that I give to the AIIE and the industrial engineering profession as a whole. It includes:

a. Contributing, in some manner, to efficient, effective government operations.

b. Reducing the over-all costs of government.

c. Making this prosperous country of ours an even better place to work, worship and play—and

d. Perhaps more than anything else, to help this great nation more effectively pave the way to lasting world-wide peace.

This takes a lot of doing, courage, sacrifice, and dedication—and YOU, the industrial engineers, more than anyone else, can make this possible—can get the job done. This is not an idle homily. It is a bold, daring, gauntlet-tossing credo especially designed for brave men. You *must* continue in your efforts to do more, to beat competition, to establish new goals, to find new approaches, to develop new techniques—and above all, *to help make a better government.* If this isn't a worthy challenge, then I've never seen one. And, unless I underestimate your talents completely, YOU—as industrial engineers, *will* meet this challenge—and get the job done in an outstanding manner. We need you —the government needs you in whatever constructive manner you may wish to contribute. How about joining the team!

THE NEXT DECADE IN OPERATIONS RESEARCH

by **HAROLD O. DAVIDSON, PH.D.**
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Dr. Davidson studied Economics and Mathematics at Northwestern University, graduated from Georgia Tech with degrees in Mechanical and Industrial Engineering, and received the Ph.D. from Ohio State. He has held positions at Georgia Tech, Ohio State, and the Johns Hopkins University.

He is the author of the AIIE monograph *Functions and Bases of Time Standards:* a Johns Hopkins monograph on the Interpretation of gamma radiation effects on mammals with application to fallout defense problems: journal articles; and research reports on a variety of military and industrial problems.

Dr. Davidson has been a Group Chairman with the Operations Research Office, and Senior Scientist with the Headquarters of the United States Army in Europe. While in the latter position he served as Scientific Advisor to the Inter-allied Tactical Study Group (NATO) and as a Technical Consultant (on loan) to the British Army in Europe.

In 1959 Dr. Davidson assumed his present position with Operations Research Incorporated, a contract research firm operating in the areas of physical sciences, life sciences, advanced engineering technology, and operations research. He is a member of AIIE, the Operations Research Society of America, is a charter member of the Institute of Management Sciences and is listed in American Men of Science.

THE NEXT DECADE IN OPERATIONS RESEARCH

by HAROLD O. DAVIDSON

Vice President, Industrial Engineering, Operations Research Incorporated

A DECADE AGO we in industrial engineering were just beginning to hear of Operations Research. Some of us were seriously exploring "OR", trying to find what it was about and how it related to industrial engineering. As many have learned since, that was no easy task.

The reason for our inquiries was a sense of deep concern over the indifferent progress that had been made in industrial engineering technology since its emergence from the Taylor era. Indeed, we were not quite sure but what an appreciable number of our group had stayed behind. The profession seemed to be resting in a state of myopic contentment, unable to visualize any role in our changing industrial society other than that it had occupied for the preceding twenty years.

About the only significant change that had occurred in the technology was a belated adoption of statistical methodology in quality control and the beginnings of its application in other areas. And even in this instance the industrial engineer seemed to fall backwards into the opportunity before he became sensible to it. The early development of statistical quality control had been done in the 1920's, yet by the beginning of World War II there was still no general awareness of its existence among industrial engineers. The nation's need for technical competence in establishing extensive statistical quality control applications in defense production was filled for the most part by mathematicians and statisticians. It seemed, in short, that industrial engineering had done a miserably ineffective job of meeting the challenges of a dynamic industrial society.

This, however, was not quite the whole story. The managements who employed industrial engineers had if anything an even more narrowly constricted view of what the industrial engineering function should be in a modern enterprise. Many, and probably a majority, used "industrial engineer" as a title for time study and work simplification technicians and through the consequences of this categorization stifled professional development. The average consulting service in the industrial engineering area during this period was only slightly superior as an avenue for professional development.

It seemed then, when we looked at Operations Research, that it might well have been sub-titled "the lost opportunities of industrial engineering." The problem areas of emergent importance in American industry and the advanced methodology that industrial engineers had ignored were being attended to by others. There was already formed an association for what was variously referred to as a new "profession" of Operations Research, or a new field of "science". Had industrial engineers lingered too long in their somnolence? Was "industrial engineering" to become, like "scientific management", an historical episode?

The answer hung by a slender thread—the newly founded American Institute of Industrial Engineers. Unassociated individuals were clearly incapable of generating a sufficiently powerful motive force for professional development of the field. Previous societies in the field of industrial engineering had failed to develop such a force. The future of industrial engineering depended, it seemed, upon the AIIE becoming at least a leading, if not a governing, instrument for professionalism in the field of practice and a stimulating agency for the development and dissemination of advanced methodology. In 1950 it was too early to be sure this would happen.

Toward the end of this decade the answer seemed assured. AIIE was not yet everything that it needed to be, but tremendous progress in the right directions had been achieved and the vitality of sustained development had been demonstrated. Another heartening development had occurred. The leading Departments of Industrial Engineering in American colleges and universities had become fully alert to the need for modernizing the curricula and hardening the technical content. Graduate programs in industrial engineering were being organized to an increasing extent around a core of advanced mathematics and "operations research" methodology courses, and a trend for graduate academic preparation for Operations Research to be centered in a Department of Industrial Engineering was clearly established. Some of the best programs developed during the decade were at the graduate level in Industrial Engineering. This was strong encouragement that in the vital area of academic preparation, industrial engineering was recovering "lost opportunities."

This development of industrial engineering in the "OR" direction was basically sound and will undoubtedly be sustained. We must not, however, misunderstand its significance. It was not, as it may have appeared, a contest for the absorption of Operations Research into Industrial Engineering, as against the establishment of a separate "OR" profession. There were, rather, two separate contests.

The challenge to industrial engineers was for professional development to the level required for effective participation in operations research activities. Because the development was required in any case for industrial engineering, and was already past due, this was a fruitful contest.

In the other contest, partisans for a new "OR profession" jousted with a quixotic challenge. At the heart of it was the (to some) disturbing recognition that the scientific pursuit of knowledge leads into the galleries of mathematical, physical, biological, and behavioral sciences. The branchings become more numerous and narrower as we pass finally into the "basic disciplines" and their sub-disciplines. They are, so to speak, like tunnels into the earth—not a part of nature's structure but a system of human artifices that enable us to conjecture parts of a structure that we are unable to know in its entirety.

To interconnect the results of these diverse probings has been a major concern of the greatest human intellects. The mechanism for doing this might be likened to imagining a connective tunnel (idea) and then attempting to establish it. Einstein's contribution of unified field theory to Physics is an example that illustrates the extreme diffulty of the objectively formal synthesis that science required. It is not surprising, then, that however much scientific knowledge we may bring to bear on a practical problem the synthesis from this knowledge of a "solution" is never an objectively formal process. Moreover, the formalisms that we do employ are admitted on something less than scientifically rigorous demonstrations of validity. It is infeasible, in fact, to apply the standards of science.* This situation prevails in any field of practice and there is associated with it the opportunity for clever manipulators of methodology to build great edifices of formalism around vacuous ideas and spurious conjectures. The more complex the formal methodology the more difficult it is for the executive to penetrate and appraise substantive content. He must rely primarily on intuitive sense of the "rightness" of results, yet in a dynamic society the executive's most important decisions may be taken on matters in which he cannot be sure how far insight from his past experience is applicable.

It is in just such situations, where operations research assistance can be most valuable to an executive, that the opportunities for charlatanry are greatest and the means of suppressing it least effective. It is relatively easy in an activity with such broad horizons and great potential for useful contributions to society for the enthusiast to become a zealot, and then by imperceptible stages of self-deception a charlatan. We are dangerously near, if not already into a deception, if we speak of Operations Research as a science rather than a practice.

When we sort out of Operations Research activity that which is Physics, Economics, Biology, and so forth there is in fact nothing left that is peculiarly "Operations Research Science." The textbooks of Operations Research are compendia of methodology for the use of practitioners, and case books of applications. Analytic model development is the major topic in the operations research periodicals. This is as it should be, but it does not constitute a substantive science of Operation Research. Newton's invention and application of the calculus *facilitated* substantive advances in Physics, but the calculus itself was not substantive Physics. In short, methodology does not make a science.

Methodology does not even make a "practice" until we begin to apply it, and we cannot do this wisely without *substantive* knowledge of the problem phenomena and of the operational environments in which the problems are situated. Applied OR studies more frequently go wrong through defects in the substantive content than through inability to find or devise a suitable methodology. There have been a number of major OR studies in the field of advanced weapon technology that produced spurious results through ignorance of major physical variables in the problem. These studies were failures in so far as the consumer of OR is concerned, for his measure of value is the reliability, timeliness, and usefulness of results—not elegance of the method.

This responsibility for substantive content in the practive of OR gives us a great deal more concern in most instances than the mechancis of analysis. The only means that we have found for assuring reliability of substantive content is through the competence and integrity of individuals in their particular fields of science and technology. This is the basis of the "multi-disciplinary approach" of operations research. It means in plain language that we need Physicists because they know Physics, Economists because they know Economics, and Industrial Engineers because they know Industrial Engineering. We are looking, moreover, not for a casual "background" but for established professional competence and integrity. So conceived, Operations Research is a *multi-professional activity.* The emphasis is on a joining of professional competences in various substantive fields rather than the suppression of these individual field identifications under a principle of common methodism such as implied by the concept of an "OR profession."

This is a somewhat extensive introduction for our proposed look at the future of Operations Research. It seemed essential, however, that we consider in some detail what the recent trends of development appear to have been. Some of these trends will continue through the coming decade. We may be sure, for example, of continuing development of analytic methodology and of the Industrial Engineer's need for knowledge of the basic mathematics that is required to appreciate and apply it. Some of this methodology will be called "Operations Research" by those who create it, some will be called "Management Science", and some will doubtless carry labels that have yet to be invented. Whatever the labels, we will need to follow these developments and select what is useful for Industrial Engineering. But methodology alone will create no new professions.

There will, however, be significant growth of multi-professional organizations and groups supporting management in pre-decision and implementation planning. Again, there will be a variety of labels (e.g. Operations Research, Systems Analysis). There will be increasing opportunities for the Industrial Engineer in this activity as it becomes more extensively involved in implementation planning. In the past these organizations have been concerned for the most part with providing "inputs" for management decision.

Much of the future growth will involve assistance to management in solving problems of implementation. There has been considerable emphasis in the nation during the past decade on advancing techno-

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*This point is developed at greater length in discussion of "The Management, Engineering, and Scientific Functions." *Journal* of Industrial Engineering, March-April, 1960. pp. 122-126.

logy as the key to economic strength and national security. It appears, however, that the most difficult problem is implementation of new technological capabilities that are developed. In the critical area of advanced weapons development, for example, it appears that Soviet success in the compression of developmental leadtime is putting to shame our supposed American "genius for organization."

In many industries, currently existing technical capabilities for greater productivity are unutilized. The locomotve fireman, for example, is still in the cab although he was technologically eliminated over a decade ago. Canadian, Russian, Japanese, and most European railroads operate with one or two in an engine crew. We, who consider ourselves a progressive people, have three for freight and switch service even as we approach a technical capability for eliminating the crews altogether.

Implementation planning cannot dissolve the political barriers to management's accomplishment of what it knows should be done. This will only come with a broader recognition among the nation's political leaders that world conditions no longer permit us to postpone our responses to changing technology for political convenience. There will always, however, be constraints of some sort so that planning for the utilization of advanced technology will include analyses of technical, economic, and organizational feasibility barriers and the identification for management of probable implementation problems and means for their solution. While the scope of this activity is multi-professional, it holds a particular challenge for the Industrial Engineer.

section 16

FAIR DAY'S WORK TIMES

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As a resident Industrial Engineer at R.C.A., Johns-Manville and E.R. Squibb and Sons, he specialized in pre-determined time study and incentive design for multi-machine assignments. Subsequently, along with his teaching at Georgia Tech and Michigan State University, he has served as Consultant to General Electric, Argus, A.M.I., Gulf States Paper Corporation, Riegel Textiles and other companies. Also, he has engaged in considerable research in development of pre-determined movement times, and in evaluation methodology for machine interference, having published some thirty papers.

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FAIR DAY'S WORK TIMES—A PROGRESS REPORT

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THE RESEARCH

The principal objective of this research is to develop, through experiment, a refined, psychologically acceptable motion time synthesis system to be called "Fair Day's Work Times." Through use of the tables to be developed, and through use of the experimental method upon which the tables are based (to establish supplementary times for skilled motions peculiar to individual plants), time study men should be able to establish highly equitable time standards for repetitive manual work. These time standards should be generally acceptable because the precise tabulated movement times upon which they will have been based will reflect the average production employee's concept of fairness.

The Film Rating Experiments, necessary to establish the average production employee's concept of fairness, to be reflected in the Fair Day's Work Time tables, have been completed. The movement timing experiments designed to provide the Fair Day's Work Times are about one-half complete. This progress report presents the results of the Film Rating Experiments and describes the movement timing experiment procedure.

THE FILM RATING EXPERIMENTS

The Objectives. The principal objective of the film rating experiments is to determine what the average U. S. industrial production employee and time study man regards as "fair day's work speed" for five simple, repetitive manual operations, some of which contain the 15 inches push-pull and the other basic movements used in speed rating the experimental subject's motion performance times in developing the Fair Day's Work movement times. For example, one of the operations is comprised solely of the 15 inches push-pull motion which is integrated with most of the aforementioned experiment motion patterns employed in developing the Fair Day's Work Times. Once the fair day's work time of this motion is determined it will be possible to convert the *factorially* expressed fair day's work times of the experimental subjects to absolute fair speed time values. A secondary usage of the results of the film rating experiments will be the development of a set of rating films to be used to teach time study men speed rating when 100 per cent speeds for the filmed operations are taken as the average concept of fair day's work speed determined by means of the experiments.

General Considerations. Joint participation of both time study men and production employees in the experiment required departure from the usual procedure of having the experimental subjects assign ratings of 80%, 105%, 120%, etc. to different successive scenes of operations projected on the movie screen. Few production employees, because of lack of rating training, would be able to rate with precision approaching that of time study men. Thus, for the sake of simplicity, it was decided to have the experimental subjects select from several scenes of different speeds simultaneously projected on a long movie screen, the speed felt to be closest to one's concept of "fair day's work" speed for the operation.

Then, there was the question of involvement of method (or motion pattern) difference in the various projected scenes of each given operation. It is recognized that motion pattern naturally changes in most operations as one increases working speed from slow to fast, the degree of such change being regulated by factors such as ballistics, rhythm possibilities, existence of motion impedences, etc. However, because of the second desired usage of the experiment results, in behalf of the Fair Day's Work Motion Time Synthesis System, it was important to involve but one variable, namely speed, rather than the two variables speed and method in the experiments. Accordingly, only operations which entailed indiscernible change of motion pattern when speeded up within the speed limits of the experiment were used in the experiment. All of the simultaneously projected scenes of each operation (representing different speeds) involved usage of film loops identical in both content and length.

There was also the problem of judgment bias and its control in planning and executing the experiments. It would be important to avoid, as much as possible, alteration of attitudes of fair day's work speeds during the orientation and execution of the experiments. Moreover, it would be important to insure against central tendency (careless selection of the middle presented choice possibilities).

Finally, since it was desired to derive conclusions from the experimental results which would reflect opinions of the average production employee and time study man in the average competitive plant in the United States, a sample of opinions representative of this situation was sought.

Experimental Equipment. Figure 1 shows the special moving picture projection equipment set up in preparation for the Film Rating Experiment. The movie projection screen measures 21 feet in length and 30 inches in height. Note that numbers, used to identify the speeds of the various simultaneously projected scenes, hang from the top of the screen.

TABLE 1.

FAIR DAY'S WORK RESEARCH PROGRAM

Summary of Results of Group Film Rating Experiments relating Production Employees with Time Study Men

Name of Operation	Weighted Average Selected "Fair Day's Work" Speed Scene 523 Time Study Men	 553 Prod. Emp.	Approx. Speed Difference of Selections
A. Gage Crank Shafts	5.476	5.785	1 545%
B. Deal Cards	5.329	5.024	1.525%
C. Grind Cylinder Heads	5.752	5.904	.076%
D. Ream Brackets	6.373	6.224	.075%
E. Carton Boxes	6.453	6.142	1.555%
Average	5.877	5.816	.305%

Eight small 16 mm. projectors (modified hand drive type) mounted on a stand and linked together with drive shafting are shown in the foreground. At the end of each shaft on the left side of each projector is a 21 tooth gear which meshes with a 20 tooth gear attached to the drive of the projector, giving a five per cent increase of speed. Thus, the speed of each projector is five per cent faster than that to the left, with two exceptions: two gear shifting devices are used to provide two desired alternate speeds (to insure against central tendency as described later) on each of two projectors.

The Movies. Note, in Figure 1, the pre-positioned black and white 16 mm. movie loops. At each projector there is an identical loop of the operation cycle of Operation A "Gage Crank shafts," also for operations B, C, D and E. Since the cycle of operation E is quite lengthy, requiring approximately 16 feet of film, loop support extensions reaching toward the ceiling are mounted on the projectors.

Each of the five operations represented by the movies is manually controlled. Originally, nine operations were photographed, at a synchronous speed of 1000 frames per minute. However, four of the operations were not used because they did not fulfill the criterion for usage in the experiments. Several cycles, performed at slightly different working speeds, were filmed for each operation. The cycles selected for making the loops for the experiment were those having no discernible erratic movements, fumbles, etc., and performed at a speed level of slightly slower than (for some operations) the same as or slightly faster (for other operations) than what was felt to be the true "fair day's work" speed. Since the actual filmed speed of 1000 frames per minute is about mid-way between the 977.01 frames per minute projected as speed No. 5 and 1025.86 as speed No. 6 of the special movie projection equipment, what was felt to be approximate "fair day's work" speeds of the five operations lie in the range from speed No. 4 to speed No. 7.

Experimental Subjects. It was planned to have 500 or more production employees and 500 or more time study men take part in the Film Rating Experiment. Actually, 567 production employees took part. Fourteen of this number apparently misunderstood the experimental procedure instructions as evidenced by their Film Rating Sheets which could not be used, thus leaving 553 production employees whose opinions were averaged. A total of 526 men with time study experience took part in the experiment, the selections of three of which cannot be used due to apparent lack of understanding of the experimental procedure instructions, leaving a net of 523 time study men whose opinions were averaged. None of the unusable results reflect seemingly extreme loose or tight concept of fair day's work speed.

The production employee participants, taken in groups of 29 to 50, represented thirteen industrial plants from Massachusetts to California and Wisconsin to Virginia. The time study men were taken in groups of 3 to 68, in 13 industrial plants and in groups of 12 to 79 in seven AIIE and I. M. S. meetings from Massachusetts to California and Wisconsin to Georgia. At these meetings, 103 companies were represented by two or more time study men and 69 by one time study man. In total, 185 industrial firms were represented by the time study men participating in the experiments. The average time study man participant had 7.33 years time study experience.

The average production employee participant had 11.83 years production experience. Approximately 61 per cent of these production employees were females. Also, approximately 60 per cent of these production employees work on wage incentive paid jobs.

Shortly before beginning each experiment involving production employees, the writer, using a roulette wheel and listings of names and-or numbers of production employees, randomly selected names of those to be invited to take part in the experiment. It is estimated that about two-thirds of the production employee participants were members of trade unions. The only criterion of qualification for a production employee participating in the experiment was that the candidate be a non-supervisory employee and be presently engaged in manual or semi-manual work. Also, only time study personnel with actual time study experience were considered participants in the experiment.

The Experiments. As the groups of experimental subjects were convened, they were first asked to carefully read the instructions on the Film Rating Sheets illustrated in Figures 2 and 3. The production employee participants were told that they were chosen by the writer's spinning a roulette wheel and using the numbers obtained to count through the lists of names or numbers of all production employees in the plant.

TABLE 2.

FAIR DAY'S WORK RESEARCH PROGRAM

Summary of Results of Group Film Rating Experiments
Involving Industrial Production Employees

Plants Visited	Average Selected Fair Day's Work Speeds and Standard Deviations (σ) of the Selections A Gage Crank Shafts	B Deal Cards	C Grind Cylinder Heads	D Ream Brackets	E Carton Boxes	Average of ABCDE	% Diff. of Avg. from Weighted Grand Avg.
Plant A (27) (High Task)	6.02 σ =1.38	5.50 σ =1.77	6.80 σ =1.03	6.92 σ =1.52	6.57 σ =1.22	6.36 $\bar{\sigma}$ =1.38	-2.72%
Plant B (32) (High Task)	6.47 σ =1.21	6.34 σ =1.23	6.81 σ =1.06	6.59 σ =1.20	6.93 σ =1.27	6.63 $\bar{\sigma}$ =1.19	-3.18%
Plant C (40)	5.10 σ =1.80	4.50 σ =1.95	5.52 σ =1.39	5.68 σ =1.82	5.85 σ =1.35	5.33 $\bar{\sigma}$ =1.66	+2.40%
Plant D (48)	5.76 σ =1.03	5.26 σ =1.02	5.81 σ =1.14	6.10 σ =1.38	6.26 σ =1.48	5.84 $\bar{\sigma}$ =1.21	- 12%
Plant E (24)	5.91 σ =2.16	4.41 σ =2.06	6.09 σ =2.08	5.86 σ =2.46	6.09 σ =2.02	5.67 $\bar{\sigma}$ =2.16	+ .73%
Plant F (32)	4.42 σ =1.59	3.85 σ =1.92	4.39 σ =1.76	5.73 σ =1.47	5.17 σ =1.51	4.71 $\bar{\sigma}$ =1.65	+5.53%
Plant G (31) (High Task)	6.10 σ =1.69	5.37 σ =1.84	6.50 σ =1.81	6.50 σ =1.69	6.50 σ =1.63	6.16 $\bar{\sigma}$ =1.73	-1.72%
Plant H (37)	6.37 σ =1.32	5.45 σ =1.56	6.10 σ =1.68	6.10 σ =1.58	6.84 σ =1.69	6.17 $\bar{\sigma}$ =1.57	-1,77%
Plant I (37)	5.68 σ =1.42	4.01 σ =1.59	5.58 σ =1.40	6.00 σ =1.07	5.89 σ =1.19	5.43 $\bar{\sigma}$ =1.33	+1.93%
Plant J (32)	5.56 σ =1.62	4.53 σ =1.86	5.47 σ =1.52	5.63 σ =1.72	5.23 σ =1.43	5.28 $\bar{\sigma}$ =1.63	+2.68%
Plant K (30)	6.10 σ =1.25	5.13 σ =1.45	5.87 σ =1.63	6.60 σ =1.33	6.33 σ =1.37	6.00 $\bar{\sigma}$ =1.41	- .92%
Plant L (39)	5.79 σ =1.11	4.94 σ =1.38	6.06 σ =1.70	6.36 σ =1.32	5.61 σ =1.19	5.75 $\bar{\sigma}$ =1.34	+ .33%
Plant L (25)	5.54 σ =1.54	5.20 σ =2.03	6.25 σ =1.39	6.54 σ =1.66	5.88 σ =1.46	5.88 $\bar{\sigma}$ =1.62	- .32%
Plant M (39)	5.73 σ =1.93	5.36 σ =1.72	6.29 σ =1.88	6.82 σ =1.71	6.05 σ =1.39	6.05 $\bar{\sigma}$ =1.73	-1.17%
Average (weighted)							1.83%

Note in Figure 3 that there is provision for the time study man's name, address and his estimate of average incentive bonus above his selected "fair day's work" speeds. Also, there is the addition of reference to wage incentives and base pay rates on the Film Rating Sheets used by the time study men, in recognition of the difference of speed rating bases (100% equals natural or normal, the high task base, etc.).

After the subjects read the Film Rating Sheets the writer demonstrated the procedure for observing the movies and filling out the sheet. He explained that the odd number scenes would be projected in the following order: 1, 3, 9, 5 and 7 and that the even number scenes would be projected in the order 2, 4, 10, 6 and 8, explaining that they would be out of true speed order to insure against careless selection of the middle projected speed. The speed of scene 2 is 5 per cent faster than that of scene 1, that of scene 3 is 5 per cent faster than that of scene 2, etc. Thus, the speed of scene 3 is 105% (105%) or 110.25% faster than that of scene 1, scene 4 is 110.25% faster than that of scene 2, etc. The experimental subjects were instructed to record 0 in any cases where they felt the fair day's work speed of an operation was less than the slowest of the simultaneously projected choices, and 11 in any cases at the other extreme. Actually, two 0 selections and one 11 selection were recorded in the total of 1076 selections.

The Experiment Results. For each operation, the selected odd speed number and even speed number were averaged, with the following exception: in those cases where the difference between the two recorded selected numbers was five or more units (reflected in selected combinations such as 1 and 6, 3 and 8, 4 and 9, etc.) the average selection for that operation was not used, the reason being strong evidence of carelessness and-or lack of ability reflected in the very low degree of judgment precision.

TABLE 3.

FAIR DAY'S WORK RESEARCH PROGRAM

Summary of Results of Group Film Rating Experiments
Involving Time Study Men

Group	Average Selected Fair Day's Work Speeds and Standard Deviations ( ) of the Selections A Gage Crank Shafts	B Deal Cards	C Grind Cylinder Heads	D Ream Brackets	E Carton Boxes	Average of ABCDE	% Diff. of Avg. from Weighted Grand Avg.
Plant A (4) (High Task)	6.00 σ =1.12	5.00 σ =1.12	5.00 σ =.87	6.25 σ =1.09	6.50 σ =1.22	5.75 $\bar{\sigma}$ =1.08	+ .64%
Plant C (3)	6.17 σ =1.69	5.50 σ =.82	7.17 σ =1.24	7.83 σ =.95	6.50 σ =1.41	6.63 $\bar{\sigma}$ =1.22	-3.77%
Plant D (9)	4.83 σ =.82	3.95 σ =1.26	5.06 σ =1.07	5.50 σ =.93	5.72 σ =1.39	5.01 $\bar{\sigma}$ =1.09	+4.34%
Plant G (32) (High Task)	6.34 σ =1.23	5.96 σ =1.33	6.63 σ =1.27	7.90 σ =1.00	6.75 σ =1.53	6.72 $\bar{\sigma}$ =1.27	-4.21%
Plant L (14)	4.79 σ =1.33	4.71 σ =.94	5.63 σ =1.49	6.50 σ =1.81	6.57 σ =1.28	5.64 $\bar{\sigma}$ =1.37	+1.19%
Plant N (29)	5.58 σ =1.86	5.57 σ =1.66	5.60 σ =1.30	6.09 σ =1.67	6.32 σ =1.42	5.82 $\bar{\sigma}$ =1.58	+ .29%
Plant O (28)	4.58 σ =1.28	4.43 σ =1.31	4.43 σ =1.69	5.43 σ =1.31	5.50 σ =1.25	4.87 $\bar{\sigma}$ =1.37	+5.04%
Plant P (50)	5.05 σ =1.43	4.30 σ =1.23	5.48 σ =1.30	5.98 σ =1.26	5.96 σ =1.13	5.35 $\bar{\sigma}$ =1.27	+2.64%
Plant Q (15)	5.30 σ =1.22	4.97 σ =1.08	6.03 σ =1.21	6.63 σ =1.67	7.10 σ =.88	6.01 $\bar{\sigma}$ =1.21	- .67%
Plant R (38)	5.79 σ =1.51	5.00 σ =1.22	5.88 σ =1.10	6.74 σ =1.16	6.21 σ =1.17	5.92 $\bar{\sigma}$ =1.23	- .22%
Plant S (31)	4.68 σ =1.17	4.23 σ =1.09	5.11 σ =1.26	5.50 σ =1.32	5.98 σ =1.52	5.10 $\bar{\sigma}$ =1.27	+3.89%
Plant T (23) (High Task)	6.63 σ =1.19	6.87 σ =1.99	7.30 σ =1.57	8.03 σ =1.34	7.38 σ =1.45	7.24 $\bar{\sigma}$ =1.51	-6.82%
Plant U (17) (High Task)	7.19 σ =1.15	6.33 σ =2.06	7.03 σ =1.75	7.43 σ =1.14	7.50 σ =.93	7.10 $\bar{\sigma}$ =1.41	-6.12%
AIIE, Atlanta Loc. (20)	5.60 σ =1.34	5.45 σ =1.55	6.05 σ =1.47	6.08 σ =1.39	6.34 σ =1.14	5.90 $\bar{\sigma}$ =1.38	- .12%
AIIE, St. Louis Conf. (12)	5.42 σ =1.65	5.08 σ =1.44	5.42 σ =1.98	6.80 σ =1.55	6.75 σ =1.79	5.89 $\bar{\sigma}$ =1.68	- .07%
AIIE, Lancaster Loc. (46)	5.44 σ =1.32	5.42 σ =1.38	5.37 σ =1.37	5.80 σ =1.36	6.30 σ =1.61	5.67 $\bar{\sigma}$ =1.41	+1.04%
AIIE, Detroit Loc. (15)	4.67 σ =1.26	4.17 σ =1.34	5.05 σ =1.46	5.38 σ =1.39	6.26 σ =1.55	5.11 $\bar{\sigma}$ =1.40	+3.84%
IMS, Chicago Loc. (79)	5.31 σ =1.68	5.49 σ =1.66	5.83 σ =1.63	6.53 σ =1.72	6.82 σ =1.61	6.00 $\bar{\sigma}$ =1.66	- .62%
IMS, Chicago Conf. (14)	5.97 σ =1.67	5.43 σ =1.24	6.17 σ =1.77	6.61 σ =1.45	6.79 σ =1.28	6.19 $\bar{\sigma}$ =1.48	-1.61%
IMS, Grand Rapids Loc. (43)	5.77 σ =1.90	5.98 σ =1.75	6.41 σ =1.67	6.67 σ =1.62	6.88 σ =1.63	6.34 $\bar{\sigma}$ =1.71	-2.32%
Average (weighted)							2.52%

Note, in Table 1, that the difference between the overall average concept of fair day's work speed of the five operations, comparing production employees with time study men, is .305%. This value was arrived at by subtracting average selected speed scene 5.816 from 5.877 and multiplying this difference by 5 per cent, the difference between speeds 5 and 6, 6 and 7, etc. Since the overall standard deviations of selections was 1.28 (or 6.68%) for all of the production employees and 1.23 (or 6.16%) for all of the time study men, there is no significant difference in the overall average concepts of fair day's work speeds for the five operations, at the .05 confidence level, comparing production employees with time study men.

Table 2 summarizes the average concepts of fair day's work speeds, and the standard deviations of selections of the 14 groups of participating production employees. Note the close agreement among the groups, of the average selected fair day's work speed scenes (average of A, B, C, D and E); the average group's overall concept differed from the weighted grand average concept by only 1.83 per cent.

Table 3 summarizes the average concepts of fair day's work speeds, and the standard deviations of selections, of the 20 groups of time study men taking part in the experiments. Note that the average group's overall concept of fair day's work speed for the five operations differed from the weighted grand average by only 2.52 per cent.

In Tables 2 and 3, "High Task" is noted for plants A, B, G, T and U. In the high task plants, employees' base pay rates (and the production efficiencies expected in return for same) are around 10% higher than those in the "normal task" plants. Thus, the average concepts of fair day's work speeds in the high task plants can be expected to be somewhat higher than those in the normal task plants, in the minds of both production employees and time study men. In recognition of this probable difference, the Film Rating Sheets (Figures 2 and 3) were so worded to attempt to cause both high and normal task persons to regard a fair day's work speed in reference to base pay rates reflecting normal task performance efficiency level. Approximately 16 per cent of the production employee participants and 20 per cent of the time study man participants work in high task plants.

Note, at the bottom of the Film Rating Sheet in Figure 3, the time study man is asked to record the per cent incentive bonus (representing the per cent the incentive paid employee would surpass the fair day's work speed level) he would expect operators in the viewed operations to average. The average of all of the estimates was 26.1% incentive bonus expectancy. The average of high task time study men (20% of sample) was 20.0% and the average of the normal task time study men (80% of sample) was 26.6%. The average selected fair day's work speed for the five operations, for the 76 high task time study men in plants A, G, T and U was 6.66, whereas it was 5.26 for the 217 low task time study men in the remaining plants visited. Comparing the difference in incentive bonus expectancy 26.6%—20%, or +6.6%) with the difference in average fair day's work speed scene concepts (6.66—5.26) x 5%, or +7.0%), we find quite close agreement. This suggests, keeping sample size limitations in mind, that the average high task time study man would set a 7% tighter time standard than would the average normal task time study man and would expect high task incentive paid employees to earn about 6.6% less bonus than normal task incentive paid employees. As previously mentioned, the high task time standard is predicated on a premium basic hourly pay rate.

Conclusions. The following information should be kept in mind in drawing conclusions from the reported results of these film rating experiments:

1. Although the experiments were geographically widely spread, all major industrial areas in the U. S. were not represented in the experiments.

2. Approximately 60% of the industrial production employee participants were females, which is probably representative for personnel on manual and semi-manual work in U. S. industry.

3. Approximately 60% of the participating industrial production employees work on wage incentive paid jobs.

4. The industrial production employees were randomly chosen by the writer from listings of names and or numbers of employees working on manual or semi-manual operations, using a roulette wheel.

5. The working force was not told of the planned experiments prior to the writer's arrival at the plant.

6. The employees took part in the experiments "on company time;" they were paid their regular pay rates while taking part in the experiment.

7. Shortly prior to the time of each experiment, the randomly selected employees were contacted by their respective foremen and were invited to take part in the experiment. Very few employees elected not to take part.

8. Upon being convened at the beginning of the experiments the writer was introduced, and then explained:
   a. The industrial production employees had to be randomly chosen and that this was done with the aid of a roulette wheel. This, then, was the only basis of their being invited to participate.
   b. The experiment procedure.
   c. The necessity of carefully deciding on selections, recording them with the indelible pencils provided and keeping them secret.

9. Averages of the experimental results were not computed until the end of all of the experiments. All of the results and averages are now on file and are available for inspection.

10. In plants A, C, and D the time study men and the production employees jointly took part in the experiments, the time study men standing in the rear.

In the writer's opinion there was very little judgment bias on the part of either the industrial production employees or the time study men taking part in the experiments. Only a very few of the 1076 Film Rating Sheets show consistently very low or very high selected fair day's work speed scene numbers. Management and labor representatives had no control over the selection procedure and the experimental procedure and, seemingly, had no desire to influence these procedures. Thus, in recognition of the aforementioned conditions relevant to these experiments, it appears there is no significant difference in the average concepts of fair day's work speeds for simple manual repetitive operations, comparing industrial production employees with time study men.

It is hoped these experimental findings will contribute toward improvement of human relations associated with industrial time study and wage incentives. Of course, these findings did provide the desired prime estimate of the fair day's work times for various fundamental movements such as the 15 inch push-pull. And, as will now be described, by rhythmically integrating (and separately timing) such movements in conjunction with various grasps, positions, etc., it is possible to make precise estimates of the fair day's work times of these latter movements.

FAIR DAY'S WORK RESEARCH PROGRAM FILM RATING SHEET

You have been chosen to take part in a research project conducted by the Department of Mechanical Engineering at Michigan State University. The purpose of this research is to determine fair day's working speeds. You are not to sign your name or put your clock number on this sheet of paper. We want to keep your opinions in complete confidence. Please do not talk with others or look at the selections of others during this experiment. Keep this sheet of paper folded except when writing down your selections.

As you closely watch the movies of the five different speeds of Operation A on the long movie screen, choose that one speed which you feel most closely represents a *fair day's working speed* for that operation. *This would be the speed at which you think this operation should be performed when the operator receives a fair day's pay and when he occasionally takes the rest time necessary for this operation.* When the movie of Operation A is over and when the room is lighted, record in the space provided on this sheet, the number of the one speed which you have selected. Next, five more speeds of Operation A will be shown on the long movie screen. Again choose the one speed you feel most closely represents a fair day's working speed for the operation and when the room is lighted write down the number of that speed in the space provided on this sheet.

Repeat this selection procedure for the other operations which are to be shown in the movies.

Thank you for your cooperation.

Sincerely,

Dale Jones,
Research Engineer
Please fill out:

How long have you been employed in industry?........

What is your present job title?...............................

What is your sex? Male ( ) Female ( )

Please record your selections in the spaces below:

Operation A, Gage Crank Shafts
Operation B, Deal Cards
Operation C, Grind Cylinder Heads
Operation D, Ream Brackets
Operation E, Carton Boxes

Selected Fair Day's Work Speeds	
Even Numbers	Odd Numbers
....	....
....	....
....	....
....	....
....	....

Figure 2. Film Rating Sheet used by production employee participants in the Film Rating Experiments

FAIR DAY'S WORK RESEARCH PROGRAM FILM RATING SHEET

For persons with time study experience

You are invited to take part in the Film Rating Experiment of the Fair Day's Work Research Program sponsored by the Department of Mechanical Engineering at Michigan State University. The purpose of this research is to determine fair day's working speeds for certain operations.

Please do not discuss or look at the selections of others during this experiment. Keep this sheet of paper folded except when writing down your selections.

As you closely watch the movies of the five different speeds of Operation A on the long movie screen, choose that one speed which you feel most closely represents a *fair day's working speed* for that operation. This would be the speed at which you think this operation should be performed when the operator receives a fair day's pay and when he occasionally takes the rest time necessary for this operation. Assume the operators are not wage incentive paid but are paid by the hour via rates that are neither higher nor lower than pay rates for like work done in neighboring plants. Be sure and consider motion *speed* only, *assuming correct motion patterns are followed in all cases.* When the movie of Operation A is over and when the room is lighted, record in the space provided on this sheet the number of the one speed which you have selected. Next, five more speeds of Operation A will be shown on the long movie screen. Again, choose the one speed you feel most closely represents a fair day's working speed for the operation and when the room is lighted, write down the number of that speed in the space provided on this sheet. Repeat this selection procedure for the other operations which are to be shown in the movies.

Thank you for your cooperation. When the experiment results are compiled your results, in comparison with the results of averages of other participants, will be mailed to you.

Sincerely,
Dale Jones
Research Engineer

Your name ....

Years Time Study Experience ....
Your address ....
....

Please record your selections in the spaces below:

Operation A, Gage Crank Shafts
Operation B, Deal Cards
Operation C, Grind Cylinder Heads
Operation D, Ream Brackets
Operation E, Carton Boxes

Selected Fair Day's Work Speeds

Even Numbers	*Odd Numbers*
....	....
....	....
....	....

Assuming these operations are wage incentive paid via the conventional one-for-one plan via refined, carefully maintained time standards, and assuming these are average qualified operators who take the allowance time reflected in the time standards, what per cent wage incentive bonus would you expect them to average over a long period of time? ....

Figure 3. Film Rating Sheet used by time study men participating in the Film Rating Experiments

MASTER CLERICAL DATA — A BREAK THROUGH IN COST REDUCTION

by **SERGE A. BIRN**
President

SERGE A. BIRN COMPANY

Mr. Birn is a Mechanical Engineering graduate from Polytechnical Institute, Carlsruhe, Germany. In 1927 he was made assistant to Mr. Wallace Clark, who is universally recognized as one of the pioneers in management engineering. Mr. Birn has been actively engaged in the consulting field ever since. In 1945 he formed the Serge A. Birn Company, a consulting firm, which is well known and respected in Europe and the United States.

Mr. Birn has been extremely active in professional organizations and has assisted in founding several chapters. He has on three different occasions been selected to represent the United States at Engineering and Professional Conferences abroad.

Among original managment developments which are Linear Responsibility Charting (LRC), Master Clerical Data (MCD). He also pioneered in the use of MTM (Methods-Time-Measurement).

MASTER CLERICAL DATA—A BREAKTHROUGH IN COST REDUCTION
or
MASTER CLERICAL DATA—CLERICAL CONTROLS WITH ECONOMY

by SERGE A. BIRN

President, Serge A. Birn Company

WHY SO little office work measurement? Office work measurement is not news. But it is certainly a rarity—even today. Why?

The easy answer—and we hear it all the time, is "It is management's fault". There is one thing wrong with this answer. It is a platitude—and like all platitudes, it simply isn't true. Let's place the blame where it belongs—on the engineering profession—no you and me. If the management of American business and industry have done so preciously little with work measurement and performance controls in offices—it is because you and I, the engineers, have failed to provide the necessary "tools" for *economic* office work measurement. If the American Space Engineers have failed to shoot successfully at the moon—it is not their fault. The fault lies somewhere in our Government, which has failed to provide the tools—or, more accurately, the money to create these tools—to shoot at the moon.

Certainly, control of office work through measurement has been going on for years, but on a most limited scale. The reason lies in *economics*. So far, the "tools", meaning the available office work measurement systems, have simply "cost too much". In fact, their cost was so high that applications were limited to only the largest companies—and only a relative few at that.

Worse even, the cost of upkeep was also exorbitant. Inevitably, a number of installations have not been properly maintained, and standards and controls disintegrated in just a few years' time.

In fact, one of the pioneers of office work measurement said some years ago that he was interested only in workers with the 500 largest corporations in America. The remaining thousands could not afford office work measurement.

THE PROBLEM GROWS

Many years ago our firm became acutely aware of this problem. We also became aware of the fact that the importance of this problem was increasing by leaps and bounds. As complexity of modern business increased — the number of white collar and white blouse workers was also steadily increasing. Today, for the first time in our history, we have more white collar workers in the U. S. than blue jean workers. And yet, the performance of some 80% or 90% of these white collar employees is not under direct control. As a result, the cost reduction picture in American business and industry is now reversed. Today more money can be saved in offices and service activities than in production.

I don't want to bore you with statistics. But our experience shows that effective controls in offices reduces the cost of routine clerical operations by 20% to 25%. Multiply this by the number of routine clerical workers employed by business, industry and Government — and you will arrive at a staggering figure. These savings alone, if realized throughout the country, could readily finance the needs of our defense establishment.

Let's say right here that IDP, EDP, computers and and related developments are only a partial answer. Computers and data processing give more, more accurate and faster information to management. Thus management is in a position to make better and faster decisions. Office cost reduction through computers, while very real in many cases, is only "a drop in the bucket" in many others. In fact, the additional useful information created by computer programming frequently creates new clerical jobs in other departments. Besides, computers will not resolve the problem of opening or distributing mail, typing letters, auditing expense reports, and so on.

A SOLUTION

In the course of factory work measurement, we quite often found it necessary to set standards for clerical work associated with factory operations, such as stock record keeping, timekeeping, shop order writing, etc. All these have their parallels in the office, and it was only natural that the measurement of the one should logically lead to consideration of measuring the other.

But logic alone is not sufficient. Ten or fifteen years ago the only readily available work measurement "tool" was the stopwatch. It was "socially acceptable" in the plant, even for *factory* clerical workers. Not so in most *offices,* where tradition and prejudice usually made the stopwatch unacceptable. Besides, time study in offices in most expensive. It never was, and it is not today, the economic answer to office work measurement.

In the recent years, most office work measurement was based on motion picture analysis — An admittedly technical procedure. Of course, if it is done once and only once to establish *basic data* — this wouldn't be too bad. But, if the procedure has to be continuously applied to similar but slightly different problems — the cost is truly exorbitant. Unfortunately, this is the way motion procedure was frequently applied.

Fortunately, we were not bound by the historical techniques of motion pictures (which are expensive) or time studies (which are both expensive and unacceptable in most offices). For years, we have been considered one of the leaders in the application of a system of predetermined motion times called Methods - Time-Measurement or "MTM", as it is better known. Since we had used MTM to solve shop paper work problems, we could not see why we could not use it to solve office work measurement problems as well.

At this point—a brief word about MTM. MTM is simply a catalog of all the motions a human being can make — whether in a plant, office, or your kitchen. To apply MTM, one simply records the motions that an employee should use to do his job — clerical or other — and adds up the times that apply to each individual motion. The result is a motion by motion description of the method and a standard or measured time for performing the job.

Of course, the conventional MTM process, as I have just outlined it, is in itself uneconomical — if used *directly* for the measurement of non-repetitive or long operations. To write motion by motion the method followed by a filing clerk in performing a thirty-minute filing job (especially if she will never again do a filing job exactly like it) would be ridiculous. But again, we were fortunate in that our application of MTM in the factory had taught us how to use it economically. We know that MTM should be used to develop motion by motion standards of operations only *in rare exceptions*. It should be used as a tool for the development of *Standard Data*. Now, MTM Standard Data is simply a catalog of *groups* of motions (rather than *individual* motions) that employees use to perform similar work. This catalog, which we developed for the measurement of office work, we called our Master Clerical Data or "MCD" for short.

The overriding importance of MCD is not that it enables you to measure office work - this has been done before. Its important is that it enables you to do it *with economy* — something which was impossible with older techniques.

SIZE NO LIMITATION

Five years ago, the idea of office cost controls based on actual measurement in a company with less than 25 clerical workers would have sounded ridiculous. Today, we have economically accomplished just such a "breakthrough" at the Precision Steel Warehouse, Inc. in Franklin Park, Illinois. Actually, this was not even planned. Some years ago, using MTM, we established time standards and installed an incentive pay system for all their warehouse workers. These men earned bonuses This being a small company, office employees knew about it. Pretty soon they started mumbling that they would like to have the same opportunity. So Orville Thaler, Precision Steel's two-fisted Treasurer, threw the problem at us.

To make a long story short, we used MCD and proved that, with an economical technique, office work measurement and incentives pay for themselves even in an office of 20 employees. Yearly savings at Precision Steel were ample to cover the cost of installation and upkeep - and yield a net saving to management.

COST OF MCD MEASUREMENT

The idea of measuring any clerical activity at an average cost of $100 per employee would have sounded ridiculous only two or three year ago. And yet, this is the average cost based on our experience with MCD installations in a number of companies, large and small.

Take for instance a large nationally known manufacturer of metal equipment upstate New York. Their Director of Systems and Procedures reported one year ago that on the average, one of their trained analysts can bring one clerical employee under full MCD control in two working days. This covers measurement, frequency studies and "feedback" to supervision.

We refer here to employees performing ten to fifteen different tasks per day. (Of course, with/highly repetitive work, such as keypunching or typing, the progress would be much faster.)

Assuming then an analyst costs $150 per week, or $30 per day — it costs $60 to measure and bring under control one clerical employee. Even if you add 100% for overhead, the cost is still only $120.

Now, let's kick this figure around a bit. One average clerical employee may cost only $3500 or $4000 here in Dallas. But in Los Angeles or New York, this cost is about $5000 (labor plus fringes). And we know from actual exprence throughout the country that performanee in American offices usually lies between 50% and 60% of normal. We also know that, with MCD controls, the performance can be increased to anywhere between 75% and 85%. The net result is a saving of at least 20% and more of ten 25%.

Only recently I checked the results of one of our first MCD installations. The Office Manager told me that one year after installation they were doing 15% *more* paperwork in their offices with 15% *less* presonnel. This is a net saving of 26%.

A 20% to 25% saving of the labor cost of one employee represents $700 to $1250 per year - or an average of $1000 per year.

The conclusion is simple. With MCD it costs about $120 to bring one clerical employee under control - and achieve a yearly saving of $1000. The ratio of savings to cost is thus about 8 to 1.

Of course, this does not include the cost of training and the cost of initial installation. The ratio between yearly savings and cost is here somewhere between 5 and 6 to 1 for the first year. And this is a one-time cost.

The low cost upkeep is equally revealing. While the cost varies from case to case, it is usually negligible.

The reason for the economy of MCD application is three-fold. First, MCD is extremely flexible. Secondly, it is very simple. Thirdly, it covers 100% of *elements* of routine office activities, so that no new MTM studies are required. One nationally known work measurement authority in the field has called it "the best set of Standard Data I have ever seen".

The simplicity of MCD is also revealed in its coding system. This coding is such that after only a few weeks of application training most of the data can be readily memorized. To our surprise, we found that rarely does an MCD analyst refer to the data directly after the initial training period.

THE FREQUENCY PROBLEM

To put it in simple words, MCD has effectively resolved the question of "how long?". The only remaining question is "how often?".

For instance how often does a typist make an erasure to correct an error? How many sheets does a bookkeeper turn in a ledger to make a posting? How many items or lines are there in your company's average invoice? How many cards does a clerk consult to find the right name in a mailing list? . . . and so on and on. Now, it is much easier to determine frequencies than to measure time. Moreover—and this is most important—it takes a less skilled person.

MCD AND EMPLOYEE RELATIONS

Another feature of MCD which surprised even us, in spite of our experience as work measurement specialists, is the excellent employee relations record MCD users have compiled. Literally hundreds of clerical workers have studied, from Winston-Salem to Chicago, from St. Louis to New York — without one single grievance or human relations problem arising as result of measurement. This is probably due to the fact that most of the information required to apply MCD is obtained from the employee actually doing the job. The Supervisor is of course consulted first but only in a general way. The Supervisor simply does not know his operations in enough detail to give the analyst an intelligent appraisal of frequencies, methods, etc. To ask him to get this information would be like asking a factory foreman to make his own time studies. If the Supervisor were called upon to give all these answers, one would simply have to hire another supervisor to do the supervising while the former supervisor gathered information.

Since the employee is the source of most information, he feels that the measurement program depends on him. He is being consulted rather than observed, and the effects on the moral must be seen to be believed.

And, remember, no one has ever been laid off as a result of an MCD installation. Attrition takes care of this.

WHAT ABOUT METHODS?

One might ask at this point "what about methods? Do you accept what the employee tells you? Don't you try to find the best way to do the best job?" Of course, we do—but, again, only where it is *economical* to do so. The vast majority of so-called methods improvements in the office never pay for themselves. Here we have a problem of semantics. Let's first define what we mean by the word "methods" as related to office work:

1. The first level is methods in terms of *motions*. What are the best motions to pick up a pen or pencil? What are the best motions to write the figure "4"? What are the best motions to pull a file out of a drawer?

   With a few exceptions it is ridiculous to try to improve office methods at this level. Doing just this was one of the serious mistakes engineers have made in the past. Since it is normal to improve methods at the level *in the shop,* most engineers have used the same approach in offices — by force of habit. This has greatly contributed to the already mentioned exorbitant cost of old office work measurement techniques—and has created employee relation and supervisory problems to boot.

   We don't even attempt to improve methods at that level. Who cares how an employee picks up a pencil, even if one set of motions is admittedly 30% or 40% faster than the other? What does it mean at the end of the day or year? Virtually nothing!
2. The next higher level of methods work in offices is office and work space layout, positioning of machines, gadgets to make the work easier, etc. I refer here to what is known as Work Simplification. Since MTM has adopted all Work Simplification principles, and since MCD is MTM adapted to office work, methods improvements of this type are very definitely considered. I would like to call them common sense improvements. They are already embodied in the MCD catalog of data.
3. The third and most important level of office methods improvements is better systems and Procedures. Tremendous savings can be made through major studies and resulting better procedures. But one does not need motion studies to make them.

   In fact, basic systems and procedures work must precede MCD application. No point setting a standard for filing 13 copies of a report if four copies will do—or if the report is not needed in the first place.

MCD TRIGGERS ADDITIONAL SYSTEMS WORK

This is a most interesting "side effect" of MCD installation. When a Systems and Procedures Analyst is trained in MCD, he suddenly finds that he has another tool in his tool kit — a "yardstick". Now he can measure the effectiveness of the new systems he dreams up without trying them out. He can do this just by visualizing the new method or system. He can devise two or three or five different ways of achieving the same result, and can compare the effectiveness of these different methods before anything is carried out.

This is quite a revelation to him. Says Mr. Joseph Blunt, Manager of Systems and Procedures and Assistant Controller of Joseph E. Seagram & Sons in New York: "We *thought* we were doing Systems and Procedures work before we had MCD. We know now that *real* Systems and Procedures work *cannot be done without measurement."*

In all our MCD installations—from the offices of a Needle Trades company in St. Louis with 100 clerical employees — to the giant Renault company in France with 68,000 employees—we found one thing. MCD—by giving a yardstick to the analyst—triggers new Systems and Procedures work. It follows like night follows the day.

Examples are many, but my time is too short. Let me give you just one.

In a large office in New York, the MCD analysts we trained studied the Expense Audit group in the

Budget Department—just those clerks and one supervisor. Measurement showed a 60% performance of the clerks. Yet the supervisor was helping them because they "had too much work".

You can't *measure* creative thinking with MCD. But you can *estimate* how long it takes. The thinking work of the supervisor consisted in auditing a *quarterly* report —once every three months. The most liberal estimate was that it took 5 days—out of 65.

Armed with these figures, the Systems man went to work. You can guess the answer. The procedure was changed. The supervisor and the quarterly report were moved to another department. One girl was promoted to Group leader. Present performance is 80% instead of 60%, net saving in hours is 25%, net saving in dollars 31%.

You might be inclined to say that you do not need MCD to find this, or that "it is not possible in my office". You are right on the first score—but this is pure theory. Not only you must have a "yardstick" to find *all* these things — but you must have this yardstick to prove them to the supervisor and to management.

WHERE DO SAVINGS COME FROM

Most of the savings come not from changing methods or improving systems, but from a ***better utilization of time.*** It is surprising how busy an office girl can look even if she performs little useful work. Even if the supervisor suspects it, he rarely can prove it so long as he has no reliable performance standards.

Historical standards — except for highly repetitive work—are no good for this purpose. Susie or Jennie have a thousand and one "legitimate" common sense reasons proving that "my work is different". And the supervisor usually finds himself in a very weak position if he tries to use historical standards to increase performance. He burns his fingers once—and, by necessity, he drops this approach. This is why we say that the term "historical standard" is a misnomer. Hysterical standards is much more descriptive.

With realistic measured standards, supervision and management can establish attainable and fair performance goals. They can determine the correct "manning" under all conditions—and they can do a better job of balancing work loads, meeting day-to-day or season-to-season "peaks and valleys". This is why good office supervisors accept MCD so readily, once they realize how the control helps them. They quickly find that the periodic performance report gives them the tool they needed so badly to effectively supervise their employees.

Most important—the employees themselves, having participated in the program, will know that their performance is estimated on a fair basis with no favoritism or personalities creeping into the picture. And the performance standards will be consistent.

SUMMARY

More than fifty yeears ago Frederick Taylor defined Scientific Management as "management based on measurement *plus control*". He also stated that controls are no better than measurement upon which they are based.

The key to true office cost control is not *good* measurement but *good and economic* measurement. If measurement is good, but its cost is prohibitive, it is of no practical value. In short, offices need measurement that does not cost too much.

It is fortunate, indeed, that inexpensive office work measurement is now available—at a time when the white collar workers exceed the blue jean workers for the first time in the history of our country. A new cost reduction horizon has been opened—and a new field of activity for engineering and Systems and Proceedures men alike.

section 18

AN AIRLINE SPARE PARTS PROBLEM

by T. K. KOLNER
Director

METHODS & SYSTEMS DEVELOPMENT
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Mr. Kolner received his B.S. and M.S. degrees in Mechanical Engineering from Case Institute of Technology. He has also done post graduate work in Law and Business at the University of Kansas City.

In addition to his present position, he has held several engineering posts with Trans World Airlines. Among these positions were Supervisor of Analysis Engineering and Supervisor of Power Plant Engineering.

Mr. Kolner is a registered professional engineer and a member of Operations Research Society and Institute of Management Sciences.

AN AIRLINE SPARE PARTS PROBLEM

by T. K. Kolner

Director, Methods and Systems Development Division, Technical Services Department
American Airlines, Inc.

INTRODUCTION

THE TASK of supplying aircraft spare parts for a commercial airline is a challenging management problem. Stocking spare aircraft components at the airport stations along the route helps reduce aircraft out of service time when component replacements are needed. However, the large number of spare parts involved and the relatively large investments required establish some limitation on how many spare parts can be procured and allocated to each station. This in turn establishes a limit on spare parts availability performance. In a large airline operation, there are usually several thousand different spare parts for each aircraft model, totaling several million dollars in investment. One category of spare parts, normally referred to in the airline industry as "Rotable Spares," will be treated in this paper. Typical rotable spare components are aircraft items, such as flight instruments, radio and radar components, pumps, wheels, engines, propellers, etc. The problem is to determine the necessary procurement volume and distribution of each rotable spare item among the field stations to achieve the lowest stock-out rate (shortage rate) for each dollar spent.

THE ROTABLE SPARE PARTS CYCLE

Figure 1 is a schematic flow diagram of the rotable spare parts. Referring to Figure 1, when field station number two (2) (Point B in Figure 1) replaces a rotable spare component on an aircraft, a serviceable unit is requested and shipped from the serviceable parts stock (A) at the depot (or Stores) to replenish the stock at station number two (2) (B). The unit removed from the aircraft is shipped from station number two (2) to an unserviceable parts pool (C) at the overhaul and repair base. The components are processed for overhaul or repair, inspection and testing (D), as required, before returning to the serviceable parts stock bin (A) at the overhaul base, thus completing the rotable spares cycle. Upon receipt of a subsequent request from any one of the field stations, the specific unit we have traced may be shipped to the requesting station thus starting on a new round through the cycle.

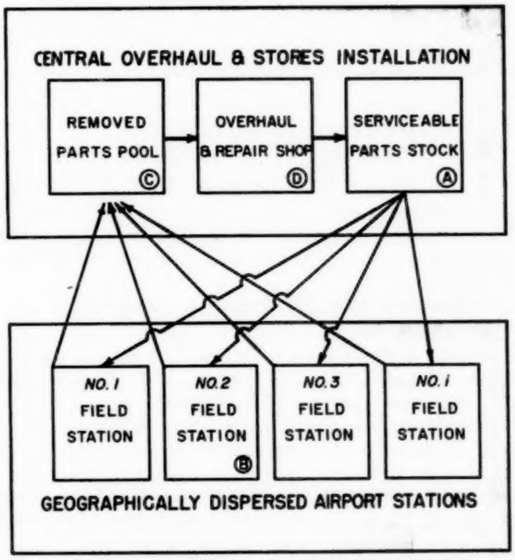

CENTRAL OVERHAUL & STORES INSTALLATION
REMOVED PARTS POOL ©
OVERHAUL & REPAIR SHOP Ⓓ
SERVICEABLE PARTS STOCK Ⓐ
NO. 1 FIELD STATION
NO. 2 FIELD STATION Ⓑ
NO. 3 FIELD STATION
NO. i FIELD STATION
GEOGRAPHICALLY DISPERSED AIRPORT STATIONS

FIGURE 1 SCHEMATIC FLOW DIAGRAM OF ROTABLE SPARE PARTS

FACTORS AFFECTING STATION STOCK PERFORMANCE

The probability of having a part shortage (stock-out) at a station is a function of the station average daily demand ( ), replenishing time ts, and the station allocated stock quantity, I,

$$Ps = f(\lambda\bullet, ts, I) \qquad (1)$$

Figure 2 illustrates where these factors occur in the replenishing cycle. The characteristics of these factors

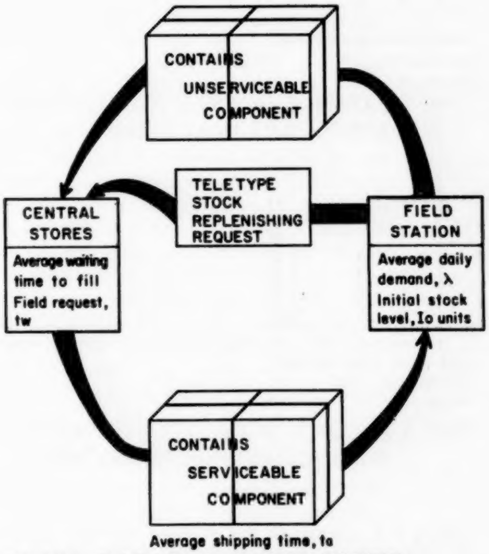

CONTAINS UNSERVICEABLE COMPONENT
CENTRAL STORES
Average waiting time to fill Field request, tw
TELETYPE STOCK REPLENISHING REQUEST
FIELD STATION
Average daily demand, λ
Initial stock level, Io units
CONTAINS SERVICEABLE COMPONENT
Average shipping time, ta

FIGURE 2 ROTABLE SPARE PARTS REPLENISHING CYCLE

are discussed below:

1. Daily Demand: Figure 3 is an actual example of the random pattern which the number of units replaced per day follows at a field station. The probability P(N) of having N number of units removed in any one day follows closely the Poisson function.

$$P(N) \qquad \overset{N}{N} \qquad (2)$$

   where λ is the average daily demand (or component replacement rate).
2. Replenishing Time: The time, ts, required to replenish the station stock level is made up of three components:
   a. The time required to transmit the stock replenishing request from the station in question to Stores (serviceable parts stock). In American Airlines, requests for rotable spare components are transmitted via private line teletype and received on punched paper tape and typed packaging slips at the Stores' warehouse in Tulsa or in New York.

   b. Waiting time to fill requests from the serviceable parts stock in Stores at the overhaul base. Normally, the requests are filled upon receipt. However, a stock-out condition in Stores will cause a delay in filling the field station request.
   c. Elapsed in-transit time from Stores at the overhaul base to the field station.

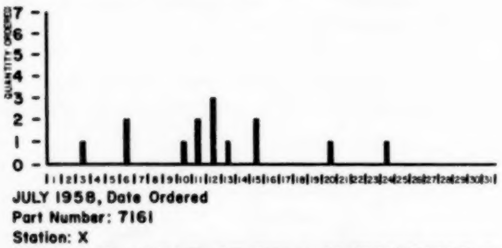


FIGURE 3 EXAMPLE OF FIELD STATION ROTABLE SPARE PART DAILY DEMAND, λ

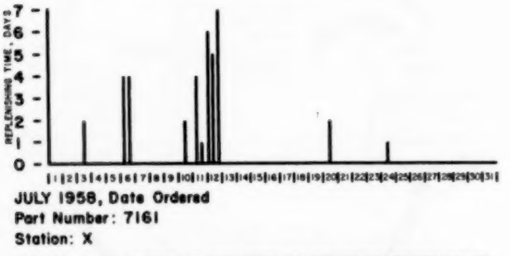


FIGURE 4 EXAMPLE OF FIELD STATION ROTABLE SPARE REQUEST REPLENISHING TIME, t_s

Figure 4 is a recap of the actual replenishing time for each request shown in Figure 3, The frequency distribution of the elapsed replenishing time of rotable spare parts can be expressed reasonably well as an exponential function.

3. Station Stock Allocation: Each station with sufficient activity is allocated a quantity of rotable spare parts. This allocation is principally an upper limit on the allowable, unassigned, "on hand" and on order stock quantity the station can have at any one time.

DETERMINING STATION STOCK-OUT PERFORMANCE

The problem of determining the probability, Ps, of a station stock-out (shortage) condition for a given value of x , Ts,I, was solved by the use of a Monte-Carlo Simulation Model programmed on an IBM 701 Computer, using the probability functions of the daily demand P(N), and exponential replenishing time function as discussed above. Figure 5 shows the results obtained from this simulation model. It is interesting to note that the probability of a stock-out condition for a given allocation is asymptotic to Ps = 0 and Ps = 1.

The expected average number of stock-out instances per year, F, for any one component at any one station can be computed as follows:

$$F=365.(\lambda).(P_s)$$

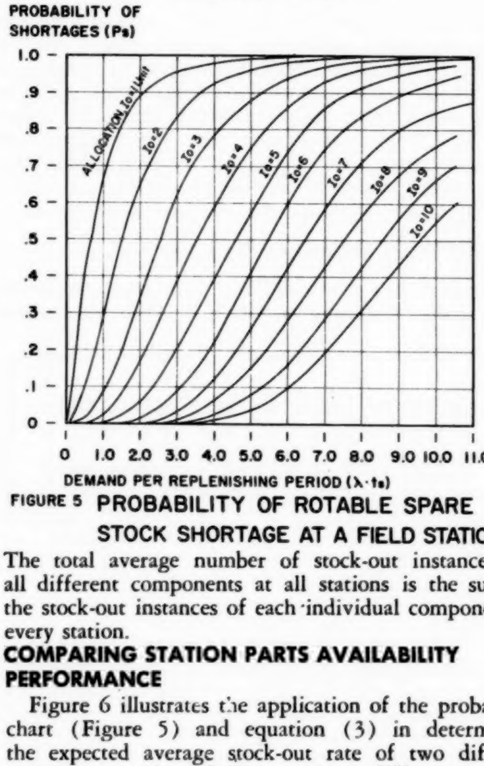


FIGURE 5 PROBABILITY OF ROTABLE SPARE STOCK SHORTAGE AT A FIELD STATION

The total average number of stock-out instances for all different components at all stations is the sum of the stock-out instances of each individual component at every station.

COMPARING STATION PARTS AVAILABILITY PERFORMANCE

Figure 6 illustrates the application of the probability chart (Figure 5) and equation (3) in determining the expected average stock-out rate of two different components (A and B), at three different stations (X, Y, and Z). It is significant to notice in Figure 6 that with additional units allocated, the reduction in stock-out rate changes for each additional unit allocated. Under certain situations, a unit allocated reduces the stock-out rate a larger amount than the unit allocated before it. However, by continuing to increase the station allocation, a point is aways reached where each additional unit allocated to a station stock above

STATION	PART NUMBER	ANNUAL COST PER UNIT ALLOCATED $	UNIT COST	AVERAGE DAILY DEMAND λ	STATION STOCK ALLO-CATION I	AVERAGE REPLEN-ISHING TIME, t_s DAYS	DEMAND PER REPLENISH-ING PERIOD $\lambda \cdot t_s$	PROBA-BILITY OF STOCK-OUT CONDITION Ps	AVERAGE NUMBER OF STOCK-OUT INSTANCES PER YEAR $F = 365(Ps)(\lambda)$	$\Delta F = F_{In} - F_{I(n+1)}$ DECREASE IN STOCK-OUT RATE WITH EACH ADDITIONAL UNIT ALLOCATED, ΔF		ANNUAL COST PER STOCK-OUT PER YEAR PREVENTED $= \frac{COST}{\Delta F}$, $
										Individual	Accumulative	
X	A	4,000.00	16,000.00	.160	0	6	.96	1.000	58.4			
X	A	"	"	.160	1	6	.96	.625	38.20	20.2	20.2	198.00
X	A	"	"	.160	2	6	.96	.290	16.90	21.3	41.5	187.00
X	A	"	"	.160	3	6	.96	.083	4.90	12.0	53.5	285.00
X	A	"	"	.160	4	6	.96	.018	1.10	3.8	57.3	1,080.00
Y	A	"	"	.027	0	3	.081	1.000	9.90			
Y	A	"	"	.027	1	3	.081	.081	.80	9.1	9.1	439.00
Y	A	"	"	.027	2	3	.081	.003	.03	.8	9.9	5,200.00
Z	B	22.50	90.00	.210	0	7	1.47	1.000	76.6			
Z	B	"	"	.210	1	7	1.47	.810	62.0	14.6	14.6	1.54
Z	B	"	"	.210	2	7	1.47	.470	36.0	26.0	40.6	.86
Z	B	"	"	.210	3	7	1.47	.190	14.6	21.4	62.0	1.05
Z	B	"	"	.210	4	7	1.47	.070	5.4	9.2	71.2	2.45
Z	B	"	"	.210	5	7	1.47	.016	1.2	4.2	75.4	5.35

FIGURE 6 STATION ROTABLE SPARE PARTS STOCK-OUT PERFORMANCE

this point reduces the stock-out rate a lesser amount than the prior allocated unit. In other words, the "payoff" of each additional unit allocated diminishes.

Dividing the cost of allocating an additional unit to a station by the reduction in expected stock-out instances per year obtained with this additional unit, gives the average cost of preventing a stock-out per year. The right hand column in Figure 6 illustrates what the average cost of preventing one stock-out instance per year would be for each additional unit allocated of part numbers A and B at stations X, Y, and Z. Although the cost of allocating a unit remains constant (assuming no price break), it is seen that the cost per stock-out instance prevented per year for part number A increases with every additional unit allocated to a station after reaching a minumum point. In case of part number A allocated to station Y, the minimum cost per stock-out instance prevented per year is realized with the first unit allocated.

DETERMINING PROCUREMENT VOLUME AND STATION ALLOCATION

With the cost of preventing a stock-cut available for every component allocated to every station as discussed above, it is possible to determine the procurement volume and the distribution of all rotable spare parts so that the smallest possible part stock-out rate is achieved for every dollar spent for spares provisioning. Figure 7 shows the inventory distribution of rotable spare components A and B among stations X, Y, and Z in consecutive order of increasing cost per stock-cut instance prevented per year. Column number 6 from the left shows the minimum part stock-out rate which can be obtained with the investment level shown on the corresponding line in the last column to the right. For example, the eleventh line from the top shows that in Figure 7 an investment of $48,720.00 in "A" and "B" rotable spare parts inventory can produce an average part stock-out rate of 14.9 instances per year provided only the parts listed above that line are procured and distributed as shown. No other volume of these three rotable spares, and no other allocation than that shown will produce a better performance for the equivalent investment, since each unit procured and distributed is selected no the basis of least cost (investment) per stock-out instance prevented.

Plotting a curve of the sixth column from the left versus the last column to the right in Figure 7 produces a graph illustrated in Figure 8. This curve gives management a "picture" of what the best possible rotable

PRIORITY	PART NUMBER	STATION ALLO-CATED TO	ANNUAL COST PER STOCK-OUT PER YEAR PREVENTED	AVERAGE NUMBER OF STOCK-OUTS PER YEAR PREVENTED	EXPECTED TOTAL AVERAGE NUMBER OF STOCK-OUTS PER YEAR	UNIT COST $	TOTAL INVESTMENT $
0					144.9		
1	B	Z	1.54	14.6	130.3	90.00	90.00
2	B	Z	.86	26.0	104.3	90.00	180.00
3	B	Z	1.05	21.4	82.9	90.00	270.00
4	B	Z	2.45	9.2	73.7	90.00	360.00
5	B	Z	5.35	4.2	69.5	90.00	450.00
6	B	Z	24.10	.9	68.6	90.00	540.00
7	B	Z	105.00	.2	68.4	90.00	630.00
8	A	X	198.00	20.2	48.2	16,000.00	16,720.00
9	A	X	187.00	21.3	26.9	16,000.00	32,720.00
10	A	X	285.00	12.0	14.9	16,000.00	48,720.00
11	A	Y	439.00	9.1	5.8	16,000.00	64,720.00
12	A	X	1,080.00	1.1	4.7	16,000.00	80,720.00
13	B	Z	4,880.00	.05	4.65	90.00	80,810.00
14	A	Y	5,200.00	.8	3.45	16,000.00	96,810.00

FIGURE 7 DISTRIBUTION OF ROTABLE SPARES INVESTMENT TO ACHIEVE SMALLEST POSSIBLE STOCK-OUT RATE PER $ SPENT.

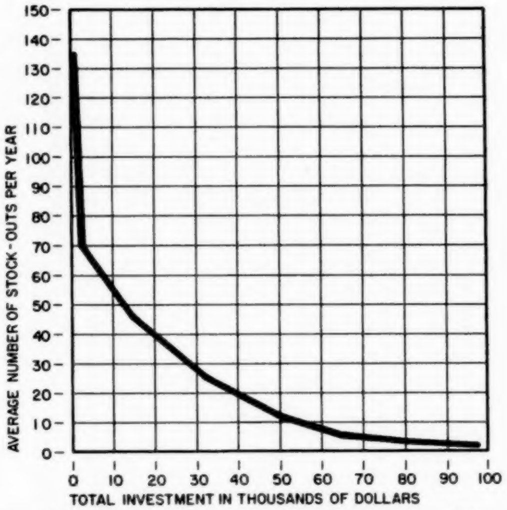


FIGURE 8 MINIMUM ROTABLE SPARES INVESTMENT REQUIRED Vs. RESULTANT TOTAL SYSTEM STOCK-OUT PERFORMANCE.

spares inventory performance of part number A and B is at stations X, Y, and Z for any level of investment.

If the exact premises for a future operation is not known, it is possible to compute several curves (like the one shown in Figure 8), one curve for each set of possible, or likely, premises. A set of curves of this nature provides management with information as to the expected outcome under various possible premises. If the cost of having stock-outs were known, it would be possible to change the graph in Figure 8 to show the optimum investment level, that is, where the sum of the cost of preventing rotable spare stock-outs and the cost of providing rotable spares is a minimum.

APPLICATION OF METHOD

The method described above can be applied to any volume of rotable spares or any number of stations. It is obvious that if any great number of parts or stations are involved, it would be practical to make use of electronic computers.

The fact that the procedure is suitable for computer application makes it possible to obtain speed in inventory planning, adjustments and control.

section 19

NEW USES AND PRACTICAL APPLICATIONS OF MATHEMATICAL PROGRAMMING

by NYLES V. REINFELD

NATIONAL INSTITUTE OF MANAGEMENT, INC.

Nyles V. Reinfeld was born in Akron, Ohio and served his apprenticeship in several Akron machine shops. Included among these shops were Portage Machine, Emmett Machine and Mechanical Mold.

He began studies at Akron University, before the war, on a part time basis, and after three years in the Navy, with service in the Atlantic and Pacific, he returned to get his Bachelor's degree.

While at Akron he received a teaching fellowship, and later received the Knight Memorial Fund award of the Beacon Journal. After Akron, he went to the University of Michigan for his Master's degree. His studies were in industrial and business management and mathematics, which with his machine shop experience, were to prove valuable in his subsequent work.

VAM: VOGEL'S APPROXIMATION METHOD

by Nyles V. Reinfeld

Managing Director Executive Services, National Institute of Management, Inc., Cleveland 14, Ohio

Reprinted from the April 1957 issue of Tooling & Production Magazine

IF YOUR first-encounter with Mathematical Programming was at the hands of a mathematician, you might very well have been tempted to substitute a D for the V in the title on the basis of its relationship. But the title is correct as given.

The three letters V-A-M stand for Vogel's Approximation Method. Mr. W. R. Vogel developed the VAM while working with me in setting up a training program in Mathematical Programming for the Federal Government.

The VAM is offered as a simplifcaton and short cut over other methods currenty in use.

The method is very simple to learn and is exceedingly fast compared to conventional methods of solution, making it very suitable to industrial adaptation. Whereas conventional methods of solution require formal training, the VAM can be learned in a matter of minutes, thus eliminating the bugaboo of mathematics found in industry.

Based on our experience, the VAM will give the best answer to applicable problems in about 80% of the cases. In the other 20%, it will usually give a very good approximation to the best answer. In these latter cases, it usually removes the "cream" of the savings to be obtained.

In addition, the VAM solution can be used as a starting point for applying conventional solutions reducing the total solution time to as much as one-fifth of that normally required.

Hence, the value of the VAM is two-fold:

1. It is easy to teach and has a quick-solution time.
2. With the solution obtained, you have a good point at which to apply more precise techniques, if the exact answer is required, again saving considerable computational time.

The problems to which the VAN applies are the typical transportation or distribution problems, which represent the bulk of all presently known applications of Mathematical Programming (MP). Many such problems exist in the normal traffic, production control, and inventory control activtes of the average manufacturng establshment.

A CASE STUDY

To illustrate the technique, let us take a look at an actual problem that was encountered at Joliet Arsenal. The problem deals with tractor-trailer movements and involves the distribution of 63 trailers to various locations for purposes of picking up loads for further distribution.

Rather than consider the complete problem here, we will only consider the problem of returning the trailers after they have been unloaded.

If a department is shipping 8 traier loads out each day, then one quirement is that 8 empty trailers must be available at that department each day to pick up the loads. The Joliet problem was further complicated, as in industry, with the use of railroad shipments, thus upsetting the balance of shipments by trucks between buildings. In other words, it was possible to haul 15 trailer loads of material out of a building each day, while only bringing in 2 trailer loads each day. The other material needed at the building was supplied by rail.

The problem of getting empty trailers back for loading is formulated below in the "Trailer Return Table," Table I.

FROM TO	1	3	64	27	NEEDED
27	-33	-25	-23	0	20
62N	-12	-26	-23	-20	7
62S	-10	-30	-20	-27	12
66	-45	-26	-50	-18	3
1	0	-24	-19	-33	7
3	-24	0	-22	-25	14
AVAILABLE	15	27	18	3	63 63

TABLE I
Trailer Return Table

Along the top of the table are listed those departments and buildings that receive truck shipments daily and therefore will have empty trailers available *from* which to draw. The number of empty trailers that will become *available* during the day at a particular building is shown at the bottom of that column. For example, at Bldg. 64, 18 empty trailers will be available each day.

Along the left side of the table are listed those departments and buildings that make truck shipments daily and therefore need trailers delivered *to* them. The number of empty trailers *needed* during the day at a particular building is shown at the far right of that column. For example, Bldg. 66 will need 3 empty trailers each day.

The figure in each of the little squares represents the time (in hundredths of an hour, based on the time study) to move an empty trailer *from* the building designated at the head of the column *to* the building designated at the left end of the row. (Because, in this example, the material being moved included ammunition, the distances between buildings were naturally fairly great.) The minus sign in front of the figures merely means that time is to be considered as costly, rather than profitable.

The problem, here formulated, represents a typical problem encountered in industry in which it is desired to reduce the total material handling time to a minimum.

METHOD OF SOLUTION

The subsequent tables in this section show the method of solution using the VAM. Please note that the VAM method of solution starts with the table in the form given by Table I and, by a series of repetitive cycles, gradually makes assignments (by rows and columns) until all needs are met. Each cycle involves a series of steps which are repeated in exactly the same manner until the answer is obtained.

In the example given here, seven cycles are required to get the final solution. The first three cycles are illustrated by Tables II, III, IV, and the last four sycles by Table V. (In actual practice, you would work with just one table and build upon it.)

To distinguish between the cycles, in each table a screen has been thrown behind the steps taken in that particular cycle. While you are first applying VAM or demonstrating it to someone else, it may be helpful for you to use a different color pencil for the action taken on each cycle. Thus: Red can be used for cycle 1, Blue for cycle 2, Black for cycle 3, Green for cycle 4, etc.

		Col. 1	Col. 2	Col. 3	Col. 4		
	FROM TO	1	3	64	27	NEEDED	Diff.
Row 1	27	-33	-25	-23	0	20	23
Row 2	62N	-12	-26	-23	-20	7	8
Row 3	62S	-10	-30	-20	-27	12	10
Row 4	66	-45	-26	-50	-18	3	8
Row 5	1	0	-24	-19	-33	7	19
Row 6	3	-24 ×	0 ⑭	-22 ×	-25 ×	14	22
	AVAILABLE	15	27	18	3	63 63	
		10	$\boxed{24}$	1	18	Difference	

TABLE II — Cycle I
Trailer Return Table

In addition, each step within a cycle has been indicated by an apppropriate symbol. These symbols are described in the step-by-step formulation below:

STEPS WITHIN THE CYCLES

Step 1: (Symbol: "Difference" column and row added to the basic table, as shown in Table II). For each row in the basic table, look at the time (cost) figures in that row and take the difference between the two smallest of these times. (If the problem were one that would provide for maximum profit, then positive figures would be used, in which case take the difference between the two highest profits.) Write this figure at the right of the row in the "difference" column.

For each column, look at the time-figures in that column and take the difference between the two smallest times (or two highest profits). Write this figure at the bottom of the column in the "difference' row.

Compute these differences for all rows and columns.

Step 2: (Symbol: □, a square enclosing a "difference" figure). Checking visually both row and column differences, select that difference which is greatest. The largest difference in cycle 1 of our example (see Table II) occurs in a column, and therefore the figure, 24, in the "difference" row is enclosed in a square.

Step 3: (Symbol: O, a circle enclosing a figure). In the column with the largest difference (24 in Table II), assign the *maximum* number of trailers to the lowest cost (or highest profit). This step is illustrated in Table II by 14. Note that the lowest cost in column two is zero, hence the assignment is to be made in the block that contains that zero. In other words, it costs nothing to move trailers *from* Bldg. 3 to Bldg. 3. But when we determine how much to assign, we must check to see how many trailers are *available* and how many are *needed* . . . in order to arrive at the number to be assigned. In cycle 1, we find that 27 trailers are available at Bldg. 3. Since we need 14 trailers at Bldg. 3, we assign 14—entering that figure in the column and encircling it.

If the greatest "difference" as indicated by a square had occurred in a row instead of a column, the assignment would have been made to the block in that row with the lowest cost (or highest profit). Hence, the procedure in either case is the same.

Step 4: (Symbol: X). When we assign trailers as indicated in Step 3, we will use up all of the trailers (available or needed) in either a row or column. In Table II, the assignment of 14 trailers to column 2, row 6, takes care of the full needs of Bldg. 3 and no more trailers need be borrowed from any other point. Hence, we cross or x-out row 6, indicating that we have used up its capacity.

		Col. 1	Col. 2	Col. 3	Col. 4			
	FROM TO	1	3	64	27	NEEDED	Diff.	Diff.
Row 1	27	-33	-25	-23	0 ③	20	23	$\boxed{23}$
Row 2	62N	-12	-26	-23	-20 X	7	8	8
Row 3	62S	-10	-30	-20	-27 X	12	10	10
Row 4	66	-45	-26	-50	-18 X	3	8	8
Row 5	1	0	-24	-19	-33 X	7	19	19
Row 6	3	-24 X	0 ⑭	-22 X	-25 X	14	22	None
	AVAILABLE	15	27	18	3	63 63		
		10	$\boxed{24}$	1	18	Difference		
		10	1	1	18	Difference		

TABLE III — Cycle 2
Trailer Return Table

SUCCEEDING CYCLES

We are now ready to start cycle 2 and we follow exactly the same steps as those above. The only change encountered is that the basic table is treated as existing of only those parts that are not x-d out (and we ignore the "difference" column and the "difference" row that we created on cycle 1). In other words, in our example, row 6 is not included in the calculation of differences for cycle 2. This will be true also in each subsequent cycle: Each time a row (or column) is crossed out, the differences are calculated only on the basis of the remaining parts of the table.

Table III shows the continuing process of what has gone before and also gives the steps used in the second cycle, as indicated by the screen background. A new "difference" column and a new "difference" row are constructed. In this case, the largest difference occurs in row one. Hence, 3 trailers are assigned to the cheapest cost (zero) in row 1. Three trailers use up all the capacity of column 4, so it is crossed out. Since 20 trailers are needed at Bldg. 27 and only 3 trailers are available there, we will have to transfer 17 more trailers to Bldg. 27 from some other point.

The differences for the third cycle will now be based upon the part of the table that has not been x-d out by the previous two cycles. The steps for the previous cycles and cycle 3 are shown in Table IV.

In cycle 3, the largest difference again occurs in a row. In fact, there is a tie between row 4 and row 5. Row 5 is selected because it has the lowest cost of the two tied rows. A number of rules have been developed for handling special cases of ties, but they will not be included here since this article is only intended to illustrate the simplicity and practicality of the technique.

The succeeding four cycles follow exactly the same pattern as that just illustrated and are given complete in Table V. Because the differences will normally change with each cycle, it is important that each cycle be completed before going on to the next. The simplicity of the procedure, however, is apparent and the actual time involved for large problems is not too great.

Recently, one problem involving a table of 37 columns and 13 rows was solved by Mr. R. W. Metzger of the GM Institute using the VAM. He estimated that, with proper application, problems of this size would take about two hours to solve by the VAM once the table was set up. The table given in our example, here, although similar, represents the total size of the problem worked on at Joliet. The figures are the original figures of the study that was initially made.

In cycle 5, we encounter something new. The greatest difference exists in row 2, where we need 7 trailers for Bldg. 62N. Since trailers from Bldg. 1 (column 1) would provide the least time factor (—12), we should draw from that point. However, running down column

		Col. 1	Col. 2	Col. 3	Col. 4				
	FROM TO	1	3	64	27	NEEDED	Diff.	Diff.	Diff.
Row 1	27	-33	-25	-23	0 ③	20	23	$\boxed{23}$	2
Row 2	62N	-12	-26	-23	-20 ×	7	8	8	11
Row 3	62S	-10	-30	-20	-27 ×	12	10	10	10
Row 4	66	-45	-26	-50	-18 ×	3	8	8	19
Row 5	1	0 ⑦	-24 ×	-19 ×	-33 ×	7	19	19	$\boxed{19}$
Row 6	3	-24 ×	0 ⑭	-22 ×	-25 ×	14	22	None	None
	AVAILABLE	15	27	18	3	63 63			
		10	$\boxed{24}$	1	18	Difference			
		10	1	1	18	Difference			
		10	1	1	None	Difference			

TABLE IV — Cycle 3
Trailer Return Table

1 we find that we have already assigned 7 trailers of the 15 available. We still have 8 left, of which 7 can be assigned to Bldg. 62N, writing the figure 7 in row 2, column 1.

Coming to cycle 6, the greatest difference exists in column 1. We need 12 trailers for Bldg. 62S (row 3), but only 1 trailer of those originally available in this column remains to be assigned. Therefore, we do not x-out the remaining squares in row 3, since we will still need 11 more trailers for Bldg. 62S.

After cycle 7, there are two blocks indicated by the heavy rectangle in the table to which no assignment has been made. Bldg. 27 still needs 17 trailers. Since all options with respect to the table have already been taken, there is no choice; we merely assign the remaining capacity to these two blocks as shown. Once this has been done, the answer so obtained is an optimum. In other words, no other method for handling these trailers would be better in terms of time.

INTERPRETATION OF THE SOLUTION

The solution says that since Bldg. 27 will have 3 trailers during the day, it will use these 3 trailers to fill part of its needs of 20 trailers a day. Bldg. 64 will send 7 of its 18 trailers to Bldg. 27 and 11 of them to Bldg. 62S, and so on.

The solution can be carried one step further by setting up routes showing the actual paths of loaded and empty trailers, if desirable. Such an extension permits a more accurate measurement of daily load in terms of tractors needed to haul the trailers, it permits a balancing of loads between drivers, and it permits a wide variation of sequencing so as to accommodate changes in schedule, delays in loading or unloading and priorities, without affecting the optimality of the end result.

Changes in the solution, reflecting change in the number of daily movements of trailers from building to building, can also be made in a matter of minutes.

		Col. 1	Col. 2	Col. 3	Col. 4								
	FROM TO	1	3	64	27	NEEDED	Diff.	Diff.	Diff.	Diff.	Diff.	Diff.	Diff.
Row 1	27	-33 ×	-25 ⑩	-23 ⑦	0 ③	20	23	$\boxed{23}$	2	2	2	2	2
Row 2	62N	-12 ⑦	-26 ×	-23 ×	-20 ×	7	8	8	11	11	$\boxed{11}$	None	None
Row 3	62S	-10 ①	-30 ×	-20 ⑪	-27 ×	12	10	10	10	10	10	10	$\boxed{10}$
Row 4	66	-45 ×	-26 ③	-50 ×	-18 ×	3	8	8	19	$\boxed{19}$	None	None	None
Row 5	1	0 ⑦	-24 ×	-19 ×	-33 ×	7	19	19	$\boxed{19}$	None	None	None	None
Row 6	3	-24 ×	0 ⑭	-22 ×	-25 ×	14	22	None	None	None	None	None	None
	AVAILABLE	15	27	18	3	63 63							
		10	$\boxed{24}$	1	18	Difference							
		10	1	1	18	Difference							
		10	1	1	None	Difference							
		2	1	3	None	Difference							
		2	1	3	None	Difference							
		$\boxed{23}$	5	3	None	Difference							
		None	5	3	None	Difference							

This is the final solution and can be proved to be optimum mathematically.

TABLE V — Cycles 4, 5, 6, 7
Trailer Return Table

CONCLUSION

The method of solution just discussed extends itself to solution of any type of Mathematical Programming problem which would be classified as a distribution problem. Since these types of problems represent a very high percentage of all Mathematical Programming problems, the VAM has a wide range of application.

The problem selected here does not illustrate all facets of the VAM. Special consideration must be given to ties and other analoguous situations for which a number of rules have been devised.

Again it should be noted that the method is an approximation and does *not* guarantee the best answer. The answers obtained are best in about 80% or more of the problems encountered so far. Sometimes, it is necessary to "polish" off the solution by use of some of the more sophisticated mathematical techniques currently in use in the field. However, even when the "polishing" is felt to be necessary, the VAM offers a short cut and solution-time savings of considerable value. When the VAM solution is best, it can be checked mathematically in a matter of minutes.

Mr. Bert Kassing of the Nekoosa-Edwards Paper Company, in discussing one of his problems, estimated that the VAM took about one-fiftieth of the time normally required by experienced persons with the mathematical method known as the MODI (Modified Distribution Method), the method most frequently used.

Because of its simplicity, we believe that the VAM will do much to foster the spread of Mathematical Programming into industry by making it a tool that everyone can use without a great deal of extensive study. In addition, it will make MP practical in those situations where time is an important factor and a computer is not a personal piece of equipment.

Previous articles authored by Mr. Reinfeld that have been published by TOOLING & PRODUCTION are: "Do You Want Production or Profit?" (Linear Programming) in August 1954, and "The Principles of Inventory Management that lead to Higher Profits" in November and December 1956, and January 1957.

section 20

OPTIMIZING THE DOLLAR COST FOR THE "SCHEDULE-CONTROL" FUNCTION

by **H. W. GEORGE**
Staff

SYSTEM DEVELOPMENT CORPORATION

Mr. George received his B.S. degree in Mathematics from M.I.T. and his M. S. degree in Mathematics from Bucknell University. He also has done graduate Industrial Engineering Study at Stevens Institute of Technology.

Prior to joining System Development Corporation, he was with Curtiss Wright Corporation as Staff Industrial Engineer. Previous consulting experience was with Stevenson, Jordan & Harrison and his own Company. Although his recent experience has been in staff activities, earlier experience was obtained in production management line positions such as Chief Engineer and Plant Manager.

OPTIMIZING THE DOLLAR COST FOR THE "SCHEDULE CONTROL" FUNCTION

by H. W. George

System Development Corporation, Santa Monica, California

THE "Schedule and Control" function herein considsidered shall include those activities which are the normal components found in Production Management. These production management operations include planning, budget development, forecasting, scheduling dispatching, receiving, stock and in-process control, inventory control, and shipping. In general, these are the necessary and important preparation and time-expedient responsibilities which determine the most effective and economical use of the available materials, men and machine integration system. Thus, in Schedule and Control operations, the complex manufacturing problem must be simplified into time-segment tasks which can be compatibly assigned to the existing productive organization.

Assuming the necessary working capital is provided for the requirements established by Schedule and Control, then the proper and timely use of the productive components is directed by the Schedule and Control function in accordance with a system or plan which has been in some manner approved by top management. Now, this transfer of the production responsibility to the Schedule-Control group or department is not done free—there is a dollar cost associated. What should top management be expected to pay for having this Schedule and Control job done?

Cost of Schedule and Control: Cost A on Chart No. 1

Chart no. 1, Dollar Cost of Control, shows the relationship between the Dollar cost of Control and the Level of Control. By Level of Control, it is meant that the relative level of the Schedule-Control Operation, namely no control, is assigned the value zero (0), and a complete Schedule-Control control over every last detail would have a value of one (1.0). The level of control which we find in actual practice will be at some value between zero (0) and one (1.0).

The annual cost for Schedule and Control will be comprised here of three (3) component costs: (1) Wages of personnel in Schedule-Control jobs; (2) Schedule-Control Facilities and supplies; and (3) Data Processing facilities.

(1) Wages of Schedule-Control personnel: These people are engaged in the Planning, Budget Preparation, Forecasting, Scheduling, Internal Servicing of Productive Entity, Finished Stores and Shipping. In the directing of the dollar expenditure and the subsequent use of the purchased and available productive components in assigned time periods, this group of people determines when to do what.

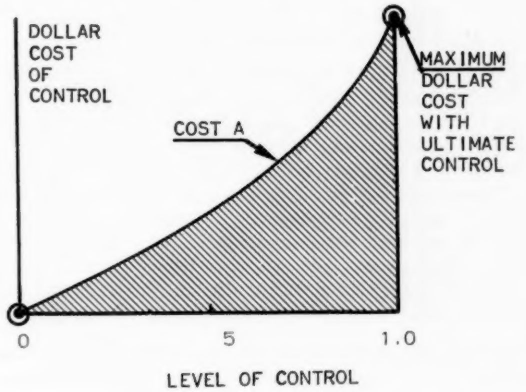
(2) Schedule-Control facilities will include files, schedule boards, communication equipment, reproduction equipment, and forms.

(3) Data Processing Facilities: The type of equipment used can be rental or purchased. In some plants, Schedule-Control activity may share the use of data processing facilities with other departments; then, the charge should be proportioned.

CHART 1

DOLLAR COST OF CONTROL

RELATED TO LEVEL OF CONTROL



The total cost for this Schedule-Control activity shall be called Cost A.

The Level of Controls The Horizontal Axis on Chart No. 1

On Chart No. 1, Level of Control is the horizontal axis with values from zero (0) to one (1.0). This concept, Level of Control, can more easily be understood from a consideration of the end or extreme conditions. First, with 100% control, we would have every part by operation controlled from the raw material procurement through assembly and finished stores to final shipping. On the other hand, the extreme opposite of 100% control will be 0%, or complete absence of control, wherein we would have no planning for work preparation or servicing of in-process requirements; this would be a production chaos, an impossible work situation. Somewhere in between these two extremes we find the average level of control, that is an intelligent, common sense level of controlling in full detail the complex part which will allow the establishment of key control points.

Cost of Control Related to the Levil of Control: Chart No. 1

This chart, No. 1 (Dollar Cost of Control), shows a zero dollar cost with a zero level of control; this is, in reality, a discontinuous point in the graph, since we have already stated this as an impossible real life situation. The 1 (or 100%) level of control has an associated cost of Maximum Dollar expenditure; this is considered as a relative point, however, the cost of maximum magnitude is probably reached by some companies which expedite their improper planning to death and so pay for inadequate control. As the level of control approaches 1., the cost will rise more quickly than at lower levels of control, since more careful and detail follow-up must be done. We are not allowing for any slipping of commitments; therefore, special or emergency work or overtime will be the remedy to correct any behind time work schedule.

The Level of Control which is maintained by the Schedule-Control operation is of major importance because of its associated dollar cost. In top quality precision manufacturing organizations, this level of control may of necessity be high, that is, near one (1.0). Whereas in commercial or comparatively lower quality production plants the Level of Control may be at a somewhat lower level, for example, .5. The processing time requirements, product complexity, and the value of the work-in-control will be of significance in initially establishing the desired working Level of Control.

Cost Associated With Inadequate Control: Cost B on Chart No. 2

This type of cost can be attributed to those causes which can be found under inadequate production mangement. Although it is possible to reduce these costs to a minimum, their complete removal is not economically feasible. Figure No. 2 shows how these costs are related to the level of control maintained. The following four types of Cost B charges will be considered: (1) Productive Labor Loss; (2) Material Loss; (3) Machine Utilization Loss; and (4) Loss of Orders through improper Schedule-Control.

(1) Productive Labor Loss: This loss occurs through hourly workers who report time against a particular part and work order. This cost in loss of productive labor would develop from Time lost in Waiting for raw and in-process material, Idle Time, Additional Set-ups, Job Chasing and Expediting, and Waiting for Tools. A large part of this cost can be hidden costs in Training, Separation, and Making Work because of Work Fluctuations instead of a leveled employment.

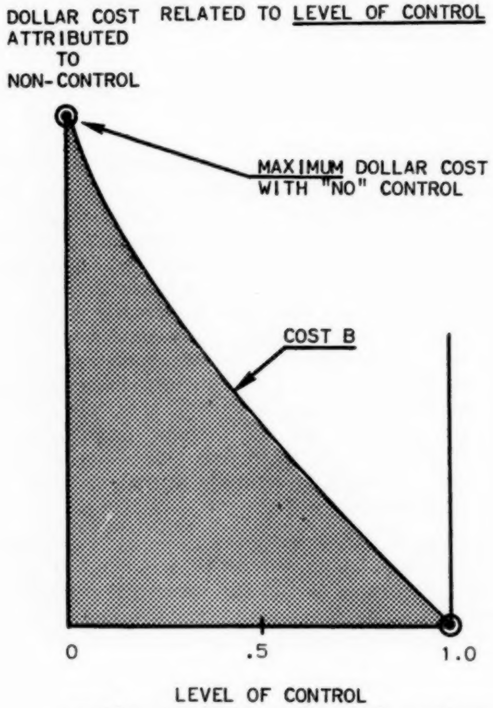
(2) Material Loss: Inadequate control of material makes for increased flow time in manufacturing with a decrease in the turnover rate of working capital in material. Incorrect material size and amount of material ordered, together with insufficient lead time for production to meet schedule—these are considered as extra costs occurring because of deficiencies in the material service function.

(3) Machine Utilization Loss: Improper balance of machine scheduling with work requirements will make Idle Machines. If it is not economical to use alternate machines for bottleneck operations, then it may be necessary to change the type of machines which can be available for the required type of work operations.

CHART 2

DOLLAR COST OF NON-CONTROL

RELATED TO LEVEL OF CONTROL



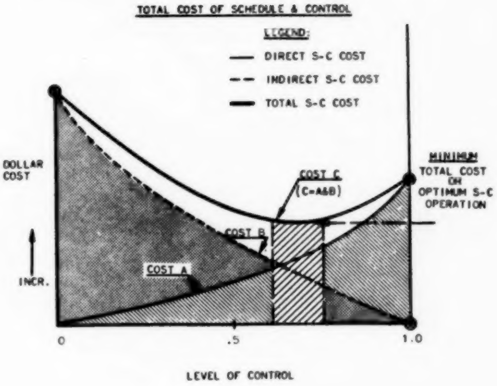
(4) Loss of Orders: Late and incomplete deliveries are sore spots with any production management function. A less critical but unwholesome condition results from excessive over shipments. Then, in the competitive market today, the best possible quality, as justified by the price, is demanded by the customer. When the manufacturing personnel are troubled by unstable employment conditions, the worker's concern is his job security and not doing his most interested and best performance. Consequently, the worker's performance is likely to be merely good enough—this does not make for satisfied customers.

In figure No. 2, the above four types of extra costs (Cost B) result from a non-control or inadequate control situation—these costs are combined in the one curve. No attempt is made in the chart to separate them. However, in the example case shown later—the four individual costs will be individually developed.

Optimizing the Dollar Cost of Control:
Note Chart No. 3—Total Cost of Schedule and Control

Two kinds of costs have been affixed to the Schedule-Control service operation, namely; (1) Cost A: The

CHART 3



cost directly assignable to the Schedule-Control Department and its activities; and (2) Cost B: The costs which occur from situations developed from INADEQUATE or NON-CONTROLLED. When these two costs—A and B—are combined into a Cost C (where $C = A + B$), the Cost C represents the total cost for which Schedule and Control can be held responsible.

Optimizing on total dollar costs, which in Figure No. 3 would be to determine the MINIMUM total dollar cost, we want the lowest point on curve C (see Figure 3). From this Figure 3, which is a typical graph, the minimum point on curve C is found in the indicated span for optimum level of control. The total dollar cost associated with this minimum point will be the target dollar cost or budgeted amount for the Schedule-Control operation. The Cost Curves A and B have a common characteristic in that in A as the 100% control level is approached (going left to right) then the related Maximum Cost is approached. Similarly, as you go from right to left along Curve B, the cost of non-control is approaching the maximum value at zero level of control.

The maximum cost on Curve B will be related to the maximum cost on Curve A in an order of magnitude greater than one (   ). This a basic reason why the Schedule and Control (Production Management) operation is economically feasible and continuing to exist. The   dollar value (Maximum Cost of Non-Control) is likely to be 2 or 3 times as great as   dollar value (Maximum Cost of Control) in going organizations.

With the above generalized approach to resolving what your Schedule-Control operation should cost, a specific example of a particular manufacturing will be considered. This we shall call Company PROFIT—and said Company has the following inherent specifications.

(This specific example will be presented and discussed during the presentation.)

NEW HORIZONS IN DESIGN OPERATIONS FOR TOMORROW'S ENGINEERING

by **R. A. FULLER**
Division Engineer

ENGINEERING DEPARTMENT
E. I. du PONT deNEMOURS & CO., INC.

Mr. Fuller is a graduate Civil Engineer from New York University. He started his engineering career in 1940 with E. I. duPont deNemours and Company, where he has held various positions in their Construction Division. In 1948 he was transferred to the Design Division in Wilmington, Delaware.

Mr. Fuller is a registered professional engineer and a member of several professional organizations.

NEW HORIZONS IN DESIGN OPERATIONS FOR TOMORROW'S ENGINEERING

by Ralph A. Fuller

Division Engineer, E. I. du Pont de Nemours & Co.

AS ENGINEERS—the future—inherently, is our business (Fig. 1)*. It takes this kind of philosophy to assure us of the new and improved products and processes that are so vital to the expanding economy of the years ahead. The future requires a technology that is constantly expanding in versatility and one that brings advantages to each succeeding generation—not enjoyed by previous ones.

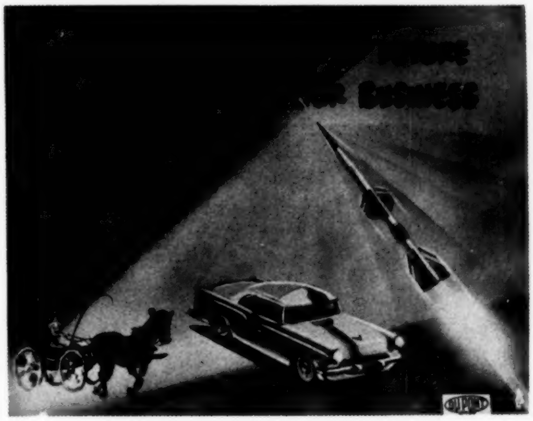


FIG. 1

Industrial Engineering has contributed greatly, it has brought impressive gains, it has enriched man's life, it has eased many of his burdens. Industrial Engineering in its role of today, offers the means by which still more impressive progress can be made in the years ahead. It is this kind of association which makes it a real pleasure to participate in your national conference and convention and its thought-provoking theme, "The '60's—A Challenge to Industrial Engineering."

A LOOK INTO THE FUTURE

I view the '60's as the underpinning, the foundation, for the years 15 and 50 years beyond. How well we design and lay this foundation may well decide the preservation of the companies for which we work—yes, it may decide our very way of life.

The fruit of test tube success in the laboratory cannot unto itself benefit your company or mine. It takes design engineering to make the results of research available for sale in the market place.

Large research outlays of both industry and government, larger in the next ten years than in all of the 160 previous years will lead to technological break-throughs not dreamed of today in electronics, metallurgy, chemistry and power generation. Markets, not existing now, may spring up overnight, and what is considered to be the stable, powerful markets of today will fall by the way-side in the wake of scientific and technological innovations. No forecast of course, can be more than a statement of probabilities—the future has to be earned.

*Note: Visual aids will be used throughout the entire presentation. Examples of the 90 slides are referred to as figures herein.

In this light, and here today, I will outline an eleven point program which improves the effectiveness of an engineering design operation. I will cover some broad concepts, some specific ideas and applications which we are pursuing at du Pont. In the course of discussion, I will indicate areas in which I believe new and greater emphasis must be applied to meet the known and unknown challenges of the future. And, I acknowledge now that it is through exchanges of know-how such as we are experiencing at this great conference, that enhances and fires up inspirations that contribute to the future progress of our nation, as well as of the organizations and companies which we represent.

DU PONT ORGANIZATION

To understand better the scope and application of the eleven point program for increased design effectiveness—a brief outline of du Pont Design Division organization, scope and size, and its relationship to the Engineering Department and Company should be helpful.

Referring to this greatly abbreviated organization chart; du Pont's Chief Engineer, Melvin F. Wood, who reports to the President, leads the Engineering Department which furnishes engineering services to 12 Industrial and 13 Auxiliary Departments.

ENGINEERING DEPARTMENT ORGANIZATION

The Engineering Department is divided into five divisions: namely, Design, Construction, Engineering Consultants, Development Engineering and Control's Accounting and Cost Estimating for the Department.

In short, the Engineering Department makes avail able to all units of the Company, its latest developments in the field of engineering.

DESIGN DIVISION ORGANIZATION

Enlarging on du Pont's Design Division, the highlight of our discussion today, it is responsible for all phases of design for new facilities. Its scope ranges from the gathering and evaluation of basic engineering data and procurement of major equipment, to the production of working drawings and specifications.

Process sections are responsible for design of process equipment and piping, and overall project coordination.

Specialists sections furnish Architectural, Structural, Civil, Power, Heating, Ventilating, Instruments, and Electrical designs for the Process Groups.

The Consultant and Development Section provides solutions to unusual engineering problems and investigates advanced design techniques.

The Management Service Section is responsible for subcontractor design and drafting, overall coordination of project scheduling, costs and cost reduction, improved methods for design operations, and development and distribution of engineering standards for Company-wide use.

Design's major role is to reduce to practice, in the form of profit making plants, most of the research data that is turned out by about 2200 technically trained people at work in 98 du Pont laboratories.

Diversity of the Company's engineering can be appreciated in that 78 du Pont plants produce about 1200 basic products or product lines. In fact, half of the Company's sales in recent years represent products that were first introduced commercially by du Pont within the past 25 years. This is a measure of progressive research and Design activity.

THE DESIGN FORCE

Presently we have 1300 engineers, designers, draftsmen and modelmakers. About 300 are contractor draftsmen employed in the New York City and Trenton, N. J. areas, and supervised by 35 du Pont designers.

When we talk about the effectiveness of a design force, we are actually talking about the utilization and the effectiveness of people that make up the force. About 80% of engineering design expense is for salaries.

Going further, the people of a design force must have imagination and drive to create new methods and skills, to use facts and logic to apply the engineered approach in transforming research into the tangibles of profit making facilities. They must have a distinct capacity for innovation.

They must work in environments that foster the attributes of creativeness, imagination and initiative, if we are to have tough-minded, aggressive design engineers producing quality engineering results. The eleven point program I will discuss is essential to the existence of this environment.

COMPUTER TECHNIQUES FOR BETTER, FASTER, DESIGN PLANNING AND SCHEDULING

To reduce the time from conception of an idea to plant operation, we telescope the research, design, construction and production phases of project work (Fig. 2). Looking at this Project Timing Chart, both the technical effort and its scheduling must be constantly evaluated during the design phase. Very close liaison and careful follow-up is required if one is to reduce time and save money.

This is accomplished at du Pont by using all sorts of devices and I'm sure most are well-known and practiced by yourselves. I will only touch upon aspects which I hope may benefit you and your work. First, operation by "Exception Reporting" and second, planning by "Arrow Diagramming."

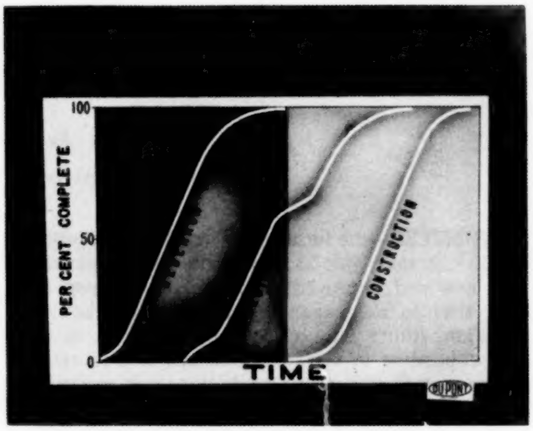


FIG. 2

POINT 1—PROJECT CONTROL BY COMPUTER PRODUCED "EXCEPTIONAL REPORTING"

To set the stage, du Pont designers are active on 500 studies and projects. With 1300 technical personnel working on such a large and diversified activity, much of it concurrently, you can appreciate the magnitude of planning and scheduling on drawings, procurement, specifications and the effective application of design manpower. Let us take a closer look at one of these activities.

For example, here is a computer produced procurement schedule. It shows scheduled date versus actual date for each phase that a procurement item progresses from "request for quotes," to purchase, to fabrication release, and for shipping to the site. Listings for our Design Division total 60,000 items monthly. For a 10 million dollar construction project, we average about 350 such sheets listing 3600 procurement items. All of this is a tremendous amount of data—meaningless, unless used effectively.

PROJECT CONTROL BY
Exception Reporting

FIG. 3

Univac computer screens these multitudes of procurement schedules and for each project produces separate "Activity" and "Exception" reports (Fig. 3). They tell us:

- —Procurement status by type of design work.
- —Delinquent items
- —Items to be procured within sixty days
- —Status of items limiting and critical to plant start-up
- —Items grouped by vendor for expediting and inspection
- —Statistical data for preparation of project status charts
- —Some ten other types of "Activity" or "Exception" reports as required

This is typical of the kind of information that is produced for control of design activity. It results in timely application of our people to project work. It puts the emphasis where it belongs.

Within the next several years we will require memory devices with capacities in the range of 500 million to one billion digits or characters. We look forward to having design information available on instant demand and randomly selective. It will further increase the utilization of our people when and where it counts.

POINT 2—DESIGN PLANNING BY "ARROW DIAGRAMMING" ON COMPUTERS

A new approach to improve design planning is the "Arrow Diagramming" technique. It was developed jointly by Remington Rand and the du Pont Co.

Inherently, engineering projects contain a technological sequence in that parts cannot be started until other parts are partially or wholly complete. Conventional charting and graphing techniques do not permit adequate analysis of thousands of details and the dynamic character of the project.

Project Planning by
ARROW DIAGRAMMING

FIG. 4

This slide illustrates the "Arrow-Diagramming" method (Fig 4). Its application starts by listing every job that has a bearing on the project. Then relationships are established—that is, what must precede each job, what follows it, and what can be run concurrently. Next inject the elements of time and cost. The prime purpose is to reduce the time taken by the project as much as costs will permit.

The magnitude of detail is large, and hence, a computer program has been developed to produce a series of optimum schedules and related costs.

On a test basis, on one of our recent projects, 1700 job arrows were used to diagram the sequence of design activity. The computer produced 56 schedules varying in overall project time from 600 to 500 work-days.

One major disadvantage is the considerable amount of input-detail required, hence before full further application of arrow-diagram to design scheduling, we are investigating ways and means to alleviate this condition.

We believe that test such as the one just outlined will result in modification or an entirely new approach to design planning as we practice it today.

MECHANIZING DESIGN COMPUTATIONS

Du Pont has made major use of computers in its engineering research work for nearly ten years and in design applications for about four years.

We believe it is worthwhile to prepare computer programs which use fundamental approaches rather than empirical formulas. The payoff comes when we are able to design less expensive plants; and, at the same time, have greater assurance that they will perform as designed.

Computers available to our design people include a Univac I, a Pace Analog, an IBM-650, a Bendix G.15, and two desk-size LGP-30's. In the area of mechanized computations I will discuss two phases that involve large applications of design effort, first the "Mechanization of Routine Design Calculations" and then, the "Use of Computers to Produce Speedy, High Quality Design Evaluations."

POINT 3—MECHANIZING THE ROUTINE OF DESIGN CALCULATIONS

Looking back over our experience, a number of factors stand out as being important to successful use of machine computation for assisting design engineers. I would like briefly to touch upon four of these. They are Management Action, Technical Adequacy, Personnel Training, and Timely Service.

To highlight the impact of these four factors on computer computation, I will use a single type of engineering calculation, the determination of what happens to a piping system when it is subjected to thermal expansion.

MANAGEMENT ACTION

About three years ago, design engineers along with management became interested in the quality of our high temperature piping designs. The systems were not failing. The question was whether the short-cut methods normally used were leading to overdesign and unnecessary investment.

Management's attitude is therefore a critical factor. If their primary concern had been with the cost of producing the designs, they would have been satisfied with short-cut hand methods. In this case, they wanted better designs leading to higher returns on investment.

TECHNICAL ADEQUACY

For piping flexibility analysis, in addition to stresses—moments and displacement calculations are necessary. Experience had taught us that thermal stresses in piping rarely damage the pipe itself. Flanges open to cause leaks. Turbines or pumps are pushed out of alignment. Walls of vessels or tanks are distorted. Hangers are snapped. Design must avoid these and other similar problems.

After analyzing our needs, we achieved a running computer program that was mathematically rigorous, technically comprehensive, and sufficiently general that it can handle more than 90% of the piping systems designed for du Pont's many types of chemical plants. This is done now by merely filling in data sheets for the computer.

PERSONNEL TRAINING

With the computer program at hand, we had to teach engineers how to use it. In the first place, it gave more detailed information on the expected performance of their designs than they ever had before. Secondly, it demanded more precise knowledge of the details of their system than the short-cut methods demanded. Finally, they had to get used to the idea that they could evaluate many alternative designs on the computer in less time than they could work through a single design by the so-called short-cut manual methods.

TIMELY SERVICE

One of the truly important features of our general-purpose computer programs, such as the one just described, is the speed with which an engineer can get results after the program is prepared.

He mails or takes computer data sheets to the computer room. He obtains printed answers within 24 hours, or he gets a computer printout calling his attention to mistakes he made in filling out the data sheets.

With these answers, he has the needed information to evaluate the adequacy of his design. He has time to consider alternatives and to look for ways to cut investment or operating costs. Inevitably, he will do a better design job.

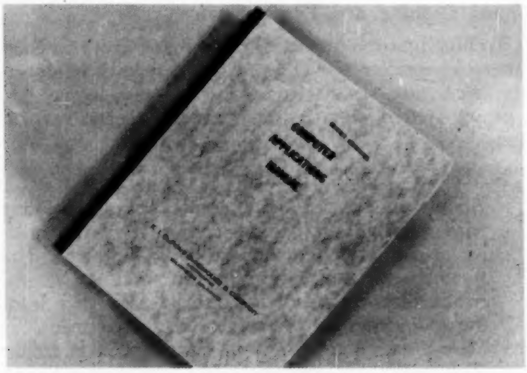


FIG. 5

Similar to calculations for piping, we have developed a wide variety of other diversified programs (Fig. 5) Included are pressure vessel design, heat exchanger rating, electrical power distribution, air duct sizing, and critical shaft speeds. More than 50 such programs are now available for use. They are summarized in the form of one-page abstracts, and the abstracts are assembled into a manual which is given wide distribution to our design force.

POINT 4—COMPUTER APPLICATION FOR PRODUCING SPEEDY, HIGH QUALITY DESIGN EVALUATIONS

In the chemical industry, process evaluation studies are a big part of our design function. However, they are often time-consuming after the idea for the alternate has been generated.

Among the methods available in attacking engineering problems, perhaps the most striking is the use of analogs to predict system performance.

Simulation
. . A PLANT AT
YOUR FINGERTIPS

FIG. 6

Analog simulation is exactly like having a miniature plant at your fingertips (Fig 6). It may be manipulated to operate nearly any way you choose, either as it should —or even as it shouldn't! While its behavior will match the plant's, the analog model operates without the limitations of a plant as to time, cost, safety, and disturbance of production.

With a simulated plant set up on a computer, different control settings can be tried 50 times an hour instead of once a shift. A dozen process changes can be simulated and evaluated at less cost than to install a hold tank or change the actual piping in a pilot plant. Emergency procedures can be tried for operations too dangerous to attempt on a real plant. Simulated upset conditions cause no real production or yield losses. Perhaps in the future, the need for high cost and time consuming pilot plants will be reduced through use of computers for low-cost plant simulation.

POINT 5—RAPID RETRIEVAL OF DESIGN DATA THROUGH DOCUMENTATION

A documentation program is underway to maximize the reuse of one of our most valuable resources—the technical information generated by Engineering Department personnel.

Key technical and economic information from du Pont projects aggregating about a billion dollars investment is being made more readily available to help solve *today's* design problems. For both past and current projects, the various unit operations in an engineering sense are segregated into information packages. They are indexed under dozens of terms which are then recorded in suitable equipment constituting a "memory."

Our engineers and designers send a wide variety of inquiries to the Engineering Information Center, such as:

—What are the alternative processes for manufacturing chemical "A"?

—Have we an existing design for an equipment item needed for a particular function?

—What are the properties of material "B"?

—Has there been an evaluation of equipment item "C" versus item "D" in a particular application?

Mechanized Information Retrieval

FIG. 7

To answer these questions, mechanized searches are made by "memory" equipment (Fig 7). Design information relative to each question is identified and its sources are furnished to the inquirer. He reviews this data for broad answers and for the location of drawings, specifications, calculations or other detailed information pertinent to solving the problems at hand.

This modern retrieval of technical information has returned benefits in many ways to our design effort. It saves time from fruitlessly searching for information. It avoids duplication of effort. It indicates areas where design development work is needed to answer a frequent question. It indicates where design changes are desirable to overcome equipment operating difficulties. It supplies the technical man the best of past knowledge for him to use as a springboard to more creative designs. In total, this program contributes materially to the accelerating effectiveness of our design force.

POINT 6—MODELS AND PHOTOGRAPHY PRODUCE FAST, QUALITY DESIGNS

Use of models is a key aid in producing economical designs for complex chemical plants. Their integration into project work has increased the ability of designers to make major engineering contributions in less time.

Our model shop area is about 6700 sq. ft. and houses up-to-date facilities. In addition there is over 5000 sq. ft. of model assembly space throughout the design working areas.

Model work in du Pont has evolved into many types. The two which I will highlight today have proven to be the most profitable. Each has a definite scope and function and each serves a specific objective. First, I will discuss the *study model,* and then, the *field transmittal model.*

STUDY MODEL

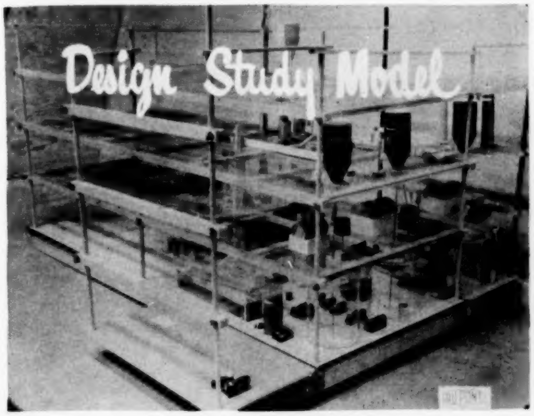


FIG. 8

The study model is conceptional (Fig. 8). It materially assists in developing the best, and the most economical layout and arrangement with minimum design effort. It expedites agreements between design functions and our clients, the Manufacturing Departments. Materials used in its construction are simple and rough. For instance, wood—plastic—wire are used to mock-up a dozen or more different arrangements before arriving at a satisfactory one. This study model work is usually done in the drafting room, by the engineer and designer.

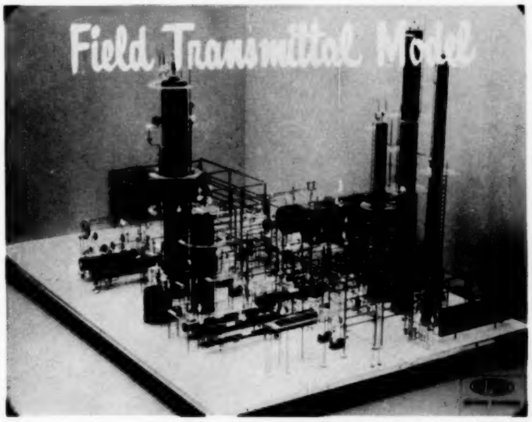


FIG. 9

FIELD TRANSMITTAL MODEL

The second type is the field transmittal model (Fig. 9). It is the result of a team effort of designers and modelmakers and is built to sufficient scale to give design information to construction. It results in better layouts and a reduction in number of drawings pertaining to piping, electrical, heating, ventilating and instrumentation as compared to conventional drawing practices for project work.

As an added dividend, they are used to train operators; determine accessibility of components, safety, evacuation procedures, and our maintenance needs. This alone has saved untold hours during process plant start-up.

PHOTOGRAPHY

Using modern photographic equipment and sensitized drafting films, we make highly useful engineering drawings of most anything that can be photographed.

Applications that significally reduce the routine drafting effort and make better use of designer talents are:

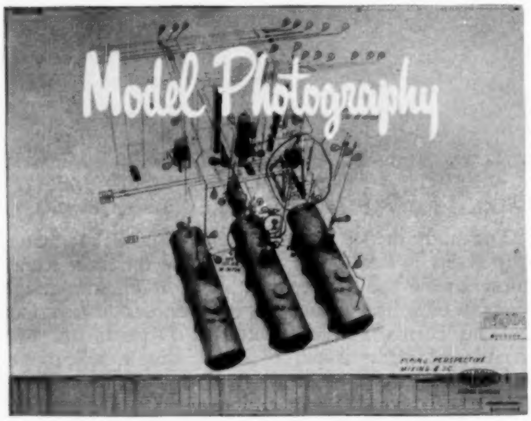


FIG. 10

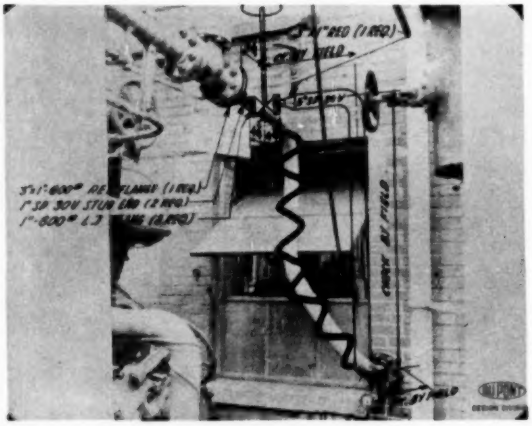


FIG. 11

—as design work proceeds on Field Transmittal Models, progress photo-drawings are issued to construction for field planning purposes (Fig. 10).

—Polaroid photographs are marked up to reflect existing conditions at plant sites in lieu of field sketching.

—photographs of existing plant conditions are converted to "Cronaflex"* photo-tracings, design data added and issued to construction showing required alteration work (Fig. 11).

The future will see an expanding application of models and photography to engineering. They initiate more creative designs, reduce routine drafting, and enhance the engineer's responsibility toward designing facilities for low investment, operating and maintenance costs.

POINT 7—INCREASING THE RESEARCH—DESIGN RELATIONSHIP

In the chemical business, things change rapidly and we must keep running to stay ahead. Out of the laboratories have come new material and techniques from which have evolved advantages never before enjoyed by previous generations. Chemical research on the part of both us and our competitors is characterized by a constant quest for new ways to exploit matter and energy.

*Du Pont Polyester Photographic Film

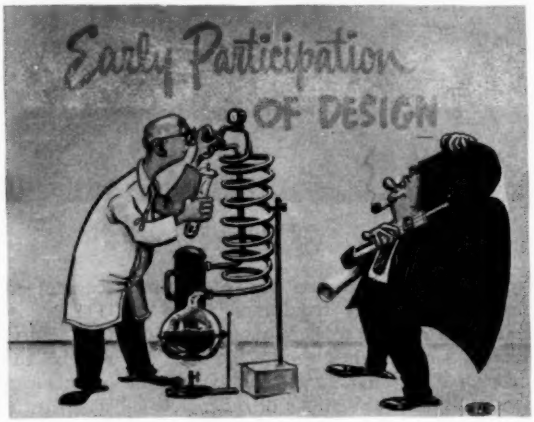


FIG. 12

To compress the "research—design phase" for optimum project benefit requires the ultimate in cooperation between research and design personnel. (Fig. 12). To achieve this cooperation, it is essential that there be early participation of design at the time the research program for a project is being organized. Normally research personnel are long on scientific training, knowledge and ability but short on plant experience, economics and commercial scale up of laboratory processes. Design can assist research programs by taking a constructive look at research proposals, and point out areas that need further exploration for practical considerations.

"Product yields" and "equipment utility" are factors which are very important in determining when a product is sufficiently developed for commercial sale. Sound design judgment can materially assist the research team to interpret and project the results into the feasibility of large-scale plants.

Design contributions can be made in the design, procurement and expediting of pilot plant installations. Design experience applied to pilot plants can shorten equipment delivery and speed up its production start-up. Such assistance permits better application of the creative potential of research engineers to creative thinking.

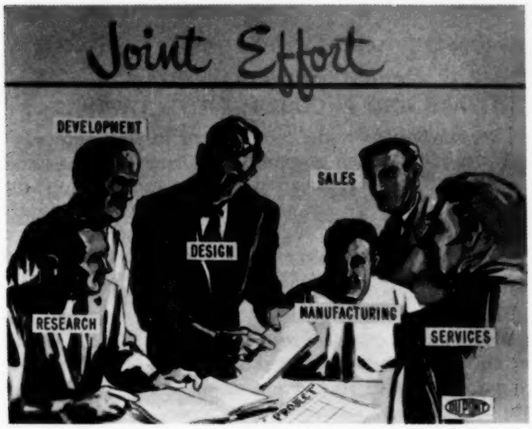


FIG. 13

We assign first-line design talent to handle key posts in the "joint-effort" approach on project work (Fig. 13). The pattern, not new to industry, permits taking maximum advantage of design know-how in the early stages of project development along with team representatives from research, manufacturing, sales and others.

We believe that during the '60's and the years beyond, close "research-design" relationships will materially reduce the time and cost of the fast growing research and development effort. It will give higher returns on investment. It will promote greater utilization of creative talents and broaden the viewpoint of both design and research engineers toward more objective goals beneficial to the overall project success. After all, research and design are both creative in obqectives, undoubtedly one more fundamental—the other more practical in approach, but their apartness does not belong in the future. The most successful ventures will find "research-design" as a closely knit team effort.

POINT 8—INCREASING THE DESIGN-CONSTRUCTION RELATIONSHIP

Project complexities and new innovations in recent years, and in the years ahead, demand increasingly stronger ties between Design and Construction if we are to achieve more economical installations.

For example low pressure air in a huge nylon bag was used to lift over 500 tons of steel struts and panels during construction of a 380' diameter dome repair shop building at Wood River, Ill. Steel crews working at ground level erected the dome from the top down as the air life raised the growing shell. Certainly, this is far different from conventional practices in the sequence of building construction and shows the types of problems that the future design and construction engineer faces. It demands a thorough understanding of each other and of each other's problems.

To further enhance relationships, we have established three active Design-Construction committees; namely, Materials Handling, Instruments and Electrical.

CONSTRUCTION
CONSULTANTS
PURCHASING
DESIGN
DU PONT
Construction
MATERIALS
HANDLING

FIG. 14

Typical for all three is the Materials Handling Committee (Fig. 14). Its organization consists of representatives from Construction, Expediting, Vendors' Inspection, Design, Engineering Consultants, and Purchasing. It meets monthly, gives wide distribution to its minutes, also issues a Materials Handling Manua.l.

Objectively these committees promote effective exchanges of design and construction information for the combined impact in solving problems. They review available materials and methods, and develop new ones, all to obtain reliable plant facilities at reduced cost.

POINT 9—DESIGN'S PART IN PRODUCTIONIZING CONSTRUCTION

Productionizing of construction work at project sites is a potent source for reducing field cost. Design plays a very important part in maximizing these savings. To illustrate, I will outline briefly the effort on a research facility nearing completion at our Experimental Station at Wilmington, Delaware.

Steps were taken early in the project to insure modular repetition of hoods, furniture, piping, ductwork, wiring and drainage. It was agreed that a model would be used and that during its development, it would be studied in minute detail by design and construction engineers as well as by research chemists. Each was given every opportunity to make his best contribution to the project.

As design progressed, changes were made to the model wherever improvements were apparent. Field engineers and craft superintendents were brought in from the construction site for consultation and advice. Concurrently construction engineers were planning for the most economical sequence of installation. Ultimately piping, ductwork and electrical systems were prefabricated on a production basis.

Here you see the pipe and duct shaft on the model. This is the pipe being fabricated at the construction field shop. The pipe and ductwork are now in place in the laboratory structure.

Admittedly every job is not a laboratory nor does it offer the same potential. However, we have applied the same principles to considerable of our work in varying degrees. Importantly, they take full advantage of the combined "know-how" of design and construction engineers.

POINT 10—ENGINEERING STANDARDS MAKE MORE TIME FOR CREATIVE THINKING

Application of . over 3400 du Pont Engineering Standards has materially advanced the effective utilization of technical forces. For example, during the past three years, design forces annually used standards on an average of 440,000 times.

They are not product standards but are tailored to engineering needs. They include design details to reduce repetitive drafting time; specifications of materials, equipment, and jobs; design data, including formulas, tables and theory to aid in solutions of engineering problems; and proven ways of doing repetitive plant maintenance and construction work.

To give you a better understanding as to how they result in large reductions in designer and drafting time —let us take a brief look at a few:

—Flashing at walls or high parapets—instead of drafting such details, the code for this standard, B 90 G, is noted on the drawing at the point of application.

—This is a standard specification and covers general requirements for pressure vessels fabricated from carbon steel—and typical of many vessel standards.

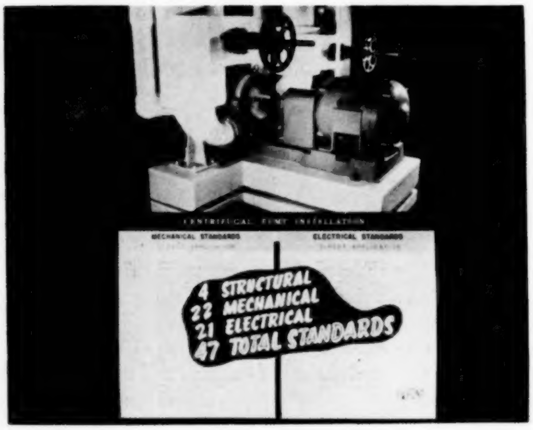


FIG. 15

To further appreciate the application of standards for reducing design work, here is a typical centrifugal pump installation (Fig. 15). Thousands of such pump installations are used in our chemical plants. Designers use about 47 structural, mechanical and electrical standards for each installation. Compare this to the repetitive drafting, calculation and specification writing that would have been required without the availability of such standards.

The standards program currently is resulting in a return of about $4.00 for every dollar spent on standards activities. They releve engineers and designers of repetitious work, and hence, promote greater concentration on creative engineering. They assist in putting plants into operation sooner.

POINT 11—POLICIES, PROGAMS THAT MOTIVATE AND ENCOURAGE EFFECTIVENESS .

Ever-continuous is the requirement to find new ways and means by which engineering talents are motivated to more effective application. Today, and certainly for the years ahead, we are a part of a civilization which has and will become progressively more complex with every achievement, every break-through in advanced technology.

The ten techniques just outlined are not the complete answer to a successful design operation. Realizing this, we encourage and promote the individual's professional growth and strive to provide incentives that will exercise his skills and talents. For example:

—it is policy to fill vacancies either through advancing or transferring engineers within the organizaton.

—Professonal development is advanced through increasing job responsibility supplemented with formal training courses, both general and technical.

—Personnel performance reviews are looked upon as opportunities for the engineer and supervisor to discuss the development of the engineer's capabilities.

—Drafting is contracted during peak workloads to minimize fluctuations in the permanent force.

—The Design Division participates in the Engneering Department's formal cost reduction and suggestion programs. They are highly organized. They inspire engineers to depart from the accustomed ways of doing things where benefits are to be gained.

—Above all and most important—we change to meet changing conditions—we practice flexibility in organization.

These are just a few of the highlights of our way of operation. We believe they go a long way toward stimulating a designer's ambition to reach greater heights as well as providing an environment for the development of his leadership potential and professional growth.

CLOSING

Today I have reviewed techniques which we consider to be only a penetration into the needs and successes of the future—there are many unexplored fields (Fig. 16).

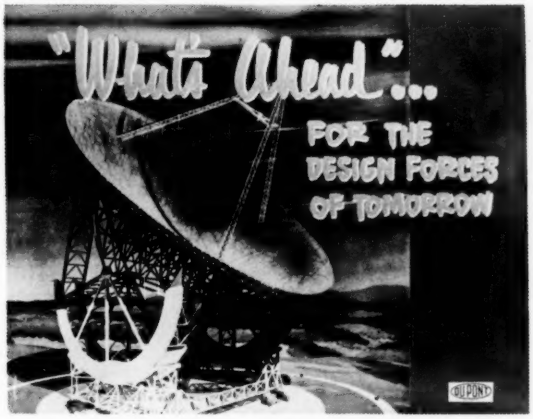


FIG. 16

."What's Ahead" for the design forces of tomorrow—most assuredly they must, and will, be breaking away from the traditions of yesterday and of today. They will be solving the complexities of laboratory achievements as well as the complexities of their own ingenuity and creativeness for the design of profit-making plants. Success heavily depends on contributions that will optimize the gains and minimize the risks.

Sometime ago, I had the pleasure of spending time with a team of industrial engineers from the United Kingdom—they visited about 75 companies representing all sections of American industry.

They were impressed by the prevailing *atmosphere* of industrial life, the *competition* between and within industries, the comparative *lack of tradition,* the willingness to try anything new and to take risks. Yes, you, we, in this great country of ours, should feel proud of what these English visitors had to say of America. And these impressions of us, must prevail not only for now but forever into the future.

Gentlemen, today has not only been a privilege, but a great pleasure for me and I can find no better way to close than by leaving this thought, "Who dares to try to paint tomorrow's masterpiece with today's brushes."

section 22

PHYSIOLOGY — PHYSICAL INPUT VS PHYSICAL OUTPUT

by W. H. M. MORRIS
PURDUE UNIVERSITY

Dr. Morris received his B.A. degree from Cambridge University and his Ph.D. degree in Agricultural Engineering from Cornell University. In academic fields he has won several scholarships for research and consultation work, both in this country and Europe.

Dr. Morris has become well known in the field of Agricultural Research and is the author of numerous major publications and reports.

THE PHYSICAL EFFICIENCY OF THE HUMAN WORKER

W. H. M. Morris

Associate Professor, Agricultural Economics
Responsible Investigator, Purdue Farm Cardiac Project

MEASUREMENT OF THE HUMAN INPUT

ENGINEERS HAVE been interested in the physical efficiency of man for many years. In the eighteenth century the physicist Coulomb computed the mechanical work done by craftsmen in a number of occupations. In the U. S. the work of Taylor on the carrying of pig iron in the yards of Bethlehem Steel Works stands out as a pioneering effort in this direction (65). Taylor also recognized that the mathematical concept of mechanical efficiency was inadequate for human work, because of the exertion of forces without moving the point of application. Taylor also studied the optimum shovel load for the maximum daily output (66). Taylor's figure of 21 pounds compares well with that of 22 pounds reported by Dressel in 1954 (18). This figure assumes that the average load will be 2-5 pounds below the capacity of the shovel.

At the time of Taylor's work in the U.S. measurement of the physical input of the human was being developed in Europe. Since then practical methods have become available for calculating the human input and so the mechanical efficiency of man. This ranges all the way from zero to about 30 percent.

We may first assume that in most industrial tasks. today the individual can perform within his physical capacity and without his body incurring an oxygen debt. This means that the worker can supply the oxygen required from his current respiratory process, without drawing on oxygen producing reserves within the body. The human input is measured directly by calorimetry. The chemistry of muscular activity is well enough understood that from the heat given out by the body as a result of activity the caloric input can be measured. This involves a large and sensitive calorimeter.

Today few of these calorimeters are in existance and most studies of the human input are made from the "fuel consumption." Since carbohydrate molecules are "burned" with oxygen to produce energy for muscular activity with the major by-products of carbon dioxide and water, it is relatively simple to measure the oxygen absorbed and the carbon dioxide produced, the so-called indirect calorimetry. A correction must be made to cover the different types of "fuel" normally burned by the U.S. worker.

Two systems of indirect calorimetry are used - a closed circuit system, in which the air is inhaled from a reservoir. The second system, which is much more common, permits the worker to inhale room air; exhaled air is collected for subsequent measurement and sampling or passd through a gasometer of some sort and continuously sampled (14, 15, 73).

There are some experimental methods for simultaneous measurement of the oxygen concentration and volume of air exhaled and obtaining th eintegral of the oxygen absorbed (11, 33).

The human input is expressed in terms of liters of oxygen per minute (about 5.0 Calories per liter of oxygen absorbed), Kilogram calories (Cal or Kcal) per minute, per task or per unit of work (foot pound performed in a specified way).

The input is correlated to the body weight or surface area, although the correlation is specific for each task depending upon the extent of movement of the body. Some workers express the input as Cal/lb body weight or Cal/sq meter body surface per hour or per task. In several of our studies it has been observed that such a correction increases the variability between subjects. Therefore, we have used Cal/min for the man or Cal per task.

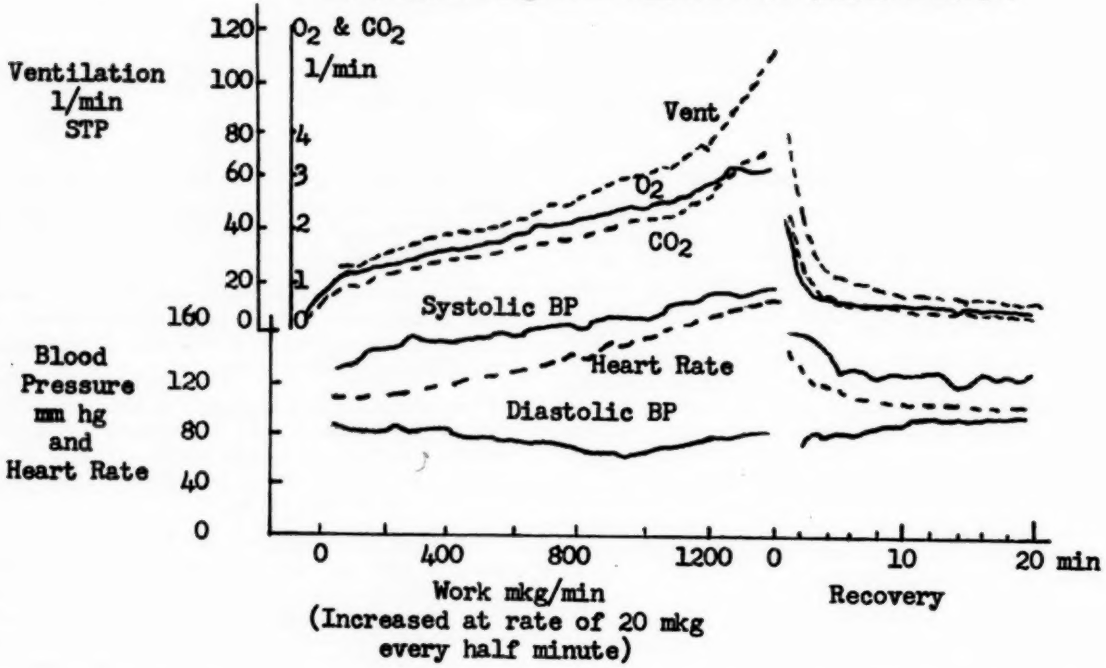
It is somewhat complex to measure energy expenditure even by indirect calorimetry and there has been a long search for simpler methods. With a relatively small loss in precision - - about 10% within workers - - the input can be estimated from the volume of air exhaled alone (20). This is effective where the same subjects are being tested performing a variety of tasks or using different work methods. Where performance is to be compared between workers, this is not recommended.

The other simple measures of the vascular system, heart rate and blood pressure, have also been used. Typical changes with increasing work load show the possibilities of these measures (Figure 1). The heart rate can be measured by hand at the wrist, by electrocardiograph, by changes in opacity of the ear lobe with every pulse cycle (46), or even by mechanical pressure changes of the temple and a microswitch (63). Several instruments are made for monitoring the rate for long periods of time.

The basis of using heart rate is that if the stroke volume does not change appreciably as the heart rate increases, the rate change is an index of the output of the heart. If the oxygen concentration in the blood is constant in arterial and in venous blood, then each pulse beat will represent an equal consumption of oxygen - the oxygen pulse; this is the oxygen uptake divided by heart rate.

Paper prepared for the 11th Annual National American Institute of Industrial Engineers Conference, Dallas, Texas May 1960.

Fig. 1 Response in Physiological Parameters to a Work Load Increasing at a Uniform Rate (after Balke,2)



In fact, the stroke volume is approximately constant over a wide range; but the oxygen pulse is not constant, ranging from about 3-4 cc per beat at rest to 16 cc and over per beat in heavy work. The venous saturation, (the oxygen content of the venous blood) decreases considerably with increase in work load; this is a major indication of increase in oxygen consumption per beat of the heart. However, there is a certain range over which the heart rate varies linearly with the oxygen consumption.

Pulse rate changes with work load. Table 1 shows that the heart rate rises in direct proportion with work over an appreciable range. There are two steps in this example: one at 14-15 beats increase/1000 f.p.m. and the second, when heavier loads are involved, at about 11 beats increase per 1000 f.p.m. This is about 15-25 percent of the resting rate. The change in energy expenditure from a change in load of 1000 f.p.m. is at least 1.5 Cal/min, about equal to the resting rate when seated.

Table 1. Relationship between Work Load and Heart Rate (55).

Work load fpm	Heart rate per min	Heart rate increment
Resting	75	30
2,000	105	27
4,000	132	22
6,000	154	23
8,000	177	21
10,000	198	

In either case it is clear that the heart rate change for a small work load, say light assembly work will be relatively small, one beat per 100 f.p.m. The pulse rate is greatly affected by posture, by environmental changes, particularly heat in an industrial setting, and by emotional tensions (17, 72). These extraneous sources of change, together with the small change in pulse rate with small work loads, make pulse rate difficult to use as an accurate measure of the human input at low levels. It remains useful at high levels of work and in estimation of the overall cardiovascular strain on the worker.

Combination of heart rate and mean blood pressure has been used as a "heart work index" (12). However, there would seem to be more justification to use heart rate multiplied by the systolic blood pressure - the pressure during the power stroke of the heart. This has been shown to be correlated with the work done by the heart muscle (54).

The sum of pulse beats above the resting rate from the end of work to recovery, the Recovery Pulse Sum, has also been used as an index of work stress (47).

The body temperature is also an indicator of the work load under a constant thermal environment. However, this requires measurement of the rectal temperaure with considerable care. The total range is of the order of about 2 degrees F, and unless the location of the sensing element is uniform, errors are introduced.

For completeness the diet method of estimating human input should be mentioned (25). In this case the total "fuel" consumed is measured or estimated, and predetermined calorific values used to estimate the total intake daily. If the individual is not gaining or losing weight the caloric intake must equal the caloric output.

Measurement of energy expenditure for longer periods, for a day's work or for a week is either made, by a dietary study (used for example with soldiers) (15, 25), or by establishing the caloric requirement for each task and the time spent during the day in the performance of each task (35, 41). We have used a work sampling procedure with random half-hour periods of observation, to estimate the daily and seasonal changes in the caloric expenditure of farmers. The calculation and analysis was done on punched card machines (46).

There is a tendency when using predetermined energy standards to underestimate the daily total (74). Wolff suggests that the error is due to failure to correct for the short periods of high load when changing from one activity to another.

It is convenient to divide the human energy input into two parts, a working and a resting. The basis for this apparent, but, in fact, at lower levels of activity it is not clearly justified. As the muscular activity begins, a shunting of the blood occurs within the body; at three times the resting level, it has reached the proportions in Table 2. The caloric expenditure in the liver is reduced by a half, and that of the stomach and intestines by one third; while that of the heart is increased threefold.

Table 2. Change in Energy Consumption Within the Body with Work Load (37).

	Resting		Working, 3x resting caloric expenditure	
Organ	Percent of total	Cal/gm/min	Percent of total	Cal/gm/min
Muscles	38.0	0.018	70.0	0.102
Liver	12.4	0.057	2.2	0.030
Stomach and Intestines	7.6	0.032	1.6	0.020
Heart	4.4	0.083	4.5	0.250
Other	37.6		21.7	
Total	100.0		100.0	

The energy used to maintain the basic bodily functions is deruced to meet the demands of the working muscles. This reduction is almost impossible to estimate. In practice it is ignored. The working energy expenditure, above resting, is particularly useful in calculation of the total energy expenditure from its component parts.

In an attempt to overcome the need for physiological measurement several research groups have developed methods for tracing the displacement of limbs, using movie film (23) or even using an electronic application of the Doppler effect, UNOPAR (49). Others have studied the mechanical reactions of the body while doing work; perhaps the first was Dr. Elaine Knowles, now Weaver, measuring the force applied to the flat iron in ironing clothes by continuously "weighing" women while ironing (32). Since that time Lauru (34), Brouha (9), Greene and myself (27), and Whitney (69) have used force sensing platforms. We correlated the forces measured with the physical work and the human energy expenditure (28).

SOME FACTORS AFFECTING THE HUMAN INPUT

The capacity of the human for work is dependent upon the duration of the task. It is about 5 1/4 Calories a minute for an eight hour shift (Table 3). This is about 0.47 hp input. However, for shorter periods it is considerably greater; for example, in running up stairs, an expenditure of 40 Cal/min might be reached for a fraction of a minute. In running the 800 meter race in a good time, say 1.83 minutes, the energy expenditure is over 60 Cal/min. Shorter distances include so much anaerobis work (oxygen debt) that the caloric expenditure does not have the same meaning. For 100 meters in 10 seconds the rate would be 300 Cal/min.

Table 3. Relationship between Recommended Maximum Work Load and Time (38).

Year	Month	Week	Day net work	Hour calories	10 min	Min	% of yearly maximum
750,000	62,500	15,000	2,500	313	52	5.2	100
	20,000	16,800	2,800	350	58	5.8	115
		18,000	3,000	357	63	6.3	121
			3,500	437	73	7.3	140
				600	100	10.0	192
					150	15.0	288
						25.0	480

It is convenient to classify work by grades but the grades of work are only approximate and depend upon definition. The values developed in Sweden, which agree well with the German standards are shown in Table 4. In the U.S. these values are generally considered too high. The Swedish "very low" is considered "low" and the Swedish "low" - "moderate" and the Swedish "moderate" - "high."

Table 4. Grades of Work and Physiological Stress (after Christensen, 13, 43).

Grade	hp input	Oxygen consumption liters, min.	Energy expenditure Cal/min	Pulse rate beats/min.	Body temperature, degrees F
Very low	1/4	0.5	2.5	75	
Low	1/4-1/2	0.5-1.0	2.5-5.0	75-100	under 99.5
Moderate	1/2-3/4	1.0-1.5	5.0-7.5	100.125	99.5-100.4
High	3/4-1	1.5-2.0	7.5-10.0	125-150	100.4-101.3
Very high	1-1 1/4	2.0-2.5	10.0-12.5	150-175	101.3-102.2
Extremely high over	1/4	2.5	over 12.5	175	over 102.2

The age of the worker has a considerable effect upon work capacity. In terms of pulse rate, a "low" level of work for the young man becomes a "moderate" level for the older man, and so on throughout the scale. The extent of this change with age using two standardized levels of work is shown in Table 5.

Table 5. Relationship between Age and Working Pulse Rate for a Sample of Swedish Steel Workers (43).

		Final Pulse Rate	
Age group years	Number of subjects	Step test 45 x 27 cm steps per minute	Bicycle ergometer 600 kgm/min
41-45	7	111	115
46-50	7	124	123
51-55	3	122	127
56-60	5	123	122
61-65	5	138	143

The change with ageing has also been expressed as a decrease in the working capacity: with a capacity of 100 percent at 25, the average man will have a capacity of 70 percent at 50 and 50 percent at 70 years (52). A considerable part of this demrease is caused by reduction in effective capacity of the lungs.

Certain physical impairments, such as coronary heart disease, may also reduce absolute physical capacity of the individual. On the other hand, studies in U.S. industry have shown that the levels of physical work involved in most jobs in which cardiacs are placed today are not beyond their physical capacity (30, 67).

The level of energy expenditure can also be used as a physiological basis for the rest pause. If the permissable sustained rate is 5.2 Calories a minute, then time spent working at above that rate must be balanced by time working below the rate to give a shift average of 5.2 Calories a minute (47, 59). This system is satisfactory for work which is dynamic in nature. Work involving holding of weights and applying pressure can better be judged by a different system, based on experiments with this particular type of work (53).

OTHER COMPONENTS OF THE HUMAN INPUT

Since the human body must be maintained during work, other variables, particularly environmental and emotional, affect the total load on the body. While it is not necessary here to deal at length with environmental stress, it will be helpful for the industrial engineer to identify some of the sources of additional strain on the human.

The human body in health must be maintained at a constant temperature, - 2 degrees F. Therefore, the heat gained, from radiation, conduction and convection, as well as from the metabloic process including performance of physical work, must equal the heat lost. Under hot conditions a little of the heat load may be dissipoted by conduction and convection but most is lost by the evaporative cooling effect of sweating. Nnder stress the heat gain is dependent on the radiant temperature or the radiation striking the worker, the wind, and the physical work load. The heat loss is also dependent upon the wind, and the vapor pressure fidderence between the skin and the air (effected by air temperature, relative humidity, and wind).

At high environmental temperatures the energy expenditure to maintain body function is increased (1) and under extreme conditions the energy expenditure for work copocity is reduced and extra rest pauses may be needed to keep the stress within normally accepted limits. A mathematical regression model combining the effect of work load and environmental stress, together with meteorological variables for prediction of energy expenditure and heart rate has been proposed by Suggs (64). However, since the model was developed with the bicycle ergometer it will require correction for application to the performance of other tasks.

Here again physiology provides a rational basis for rest schedules, which should serve to reduce the stress from the shift - - conveniently measured as the sweating rate - - below thepermissable maximum, probably one one liter per hour (71). The sweating rate can be predicted by several empirical relationships and nomographs (4, 44). In practce it s noted that frequent short rests are much more effective than the same time spent in fewer longer rests; during longer rests there is a tendency to stop sweating, which greatly reduces the rate of thermal recovery. Recovery will take place more rapidly, if rest pauses are spent in an arair-conditioned area (8).

A noticeable reduction of work capacity is expected when the weight loss exceeds 1 - 2% of the body weight (43). Other environmental factors such as vibraton effect the energy expendture, for example while driving a tractor (21, 40) or a truck.

The emotional stress, together with the psychological environment - - noise and similar items - - affect the human and add to the cardiovascular load and fatigue (72). However, there is no quantitative approach to these stresses. The surgeon, operatng with a relatively low work stress but a high emotional stress, may have three to four times thhe heart work (heart rate x systolic blood pressure) of the steel mill worker (Table 6.)

Table 6. Heart Work Increase in Steelworker and Surgeon (24).

		Working increase in		
	Cal/min	Blood pressure	Pulse	Heart work
Steelwor*ker*	4.4	10	61	610
Surgeon	3.0	80	35	2800

MEASUREMENT OF THE OUTPUT

Strictly mechanical efficiency of the human body will be the work output divided by the input. Work output is, of course, the force applied multiplied by the distance moved by the point of application. It can be positive or negative, when work is done on the body, for example, lowering a load or walking downstairs.

In fact, it requires human energy merely to apply the force, regardless of movement of the point of application. The anomalous phrase "static work" has been used to describe this type of human "work." Its mechanical efficiency is inevitably zero. However, the human energy expenditure can be closely correlated with the force applied and the frequency of application (28).

EFFICIENCY

As early as 1901 Johansson (31) proposed that in performing a certain task with a variable work load under laboratory conditions, say, riding a bicycle ergometer, the human input was expressed by Eo + aW, where Eo is the resting energy expenditure, a is a constant and W the work load. This holds until the musculature required to perform the work must be increased. The energy expenditure per unit of work then increases exponentially to the limit of the respiratory or circulatory capacity to absorb oxygen. Only in the case of using major muscle groups, such as the legs, can the oxygen absorption of the body become limiting (19).

The greatest physical efficiency in the short run is at the highest sustainable load. Physiologists suggest that the optium pace is the highest pace which the individual can sustain without getting out of breath. The range of efficiency that is found in human "work" as already mentioned, is from 0 to about 30 percent. Examples from E. A. Muller (Figure 2) show that cycling is the most efficient form of work, with pushing a load next. The least efficient are heavy lifting and pushing tasks. The capacity of man for periods of an hour is the order of 10 Cal/min (Table 3, page 6) above this the efficiency generally declines.

If the work is even heavier so that the energy expenditure cannot be met without incurring an oxygen debt, the efficiency of work is greatly decreased. The so-called anaerobic work (for example, running 100 yard dash) is performed at half or less the efficiency of aerobic work.

Experiments on isolated muscle preparations show that 40 percent of the energy liberated in the muscle appears in the initial contraction and 60 percent in the recovery (56). This makes no allowance for maintenance of the body, or supplying the blood and removing the waste products from the muscle. The potential efficiency is therefore less than 40 percent.

The relationship between work load and efficiency is not only dependent upon the level of energy expenditure but also on pace. The optimum pace of walking has been studied by several research groups (5, 7, 62). Typical results show a minimum energy expenditure per foot of travel, about 2½ mph (Table 7).

Fig. 2 Efficiency of Performing Different Tasks (E. A. Müller, 39)

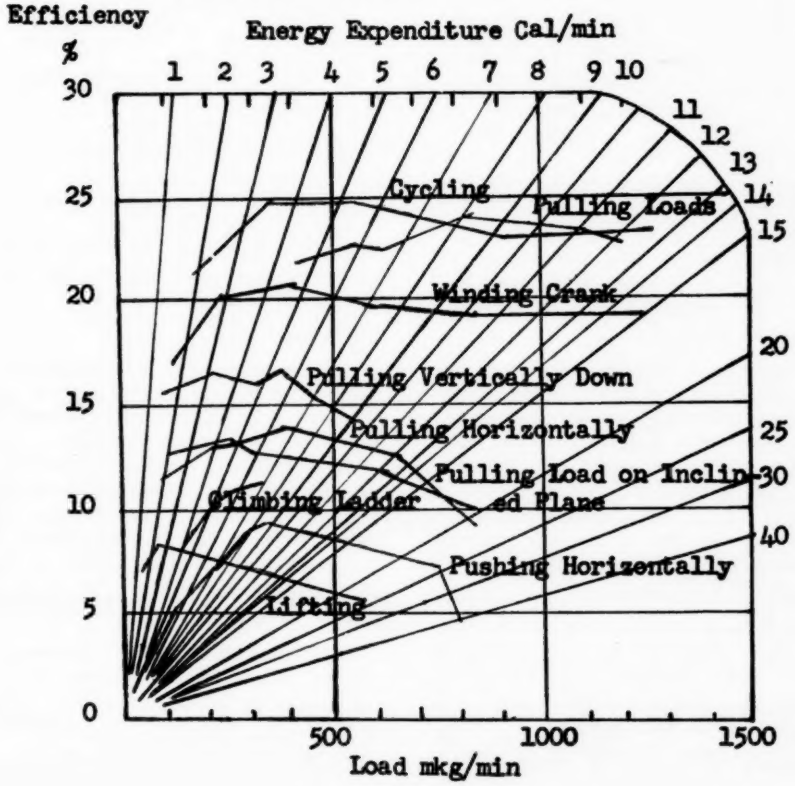


Table 7. Energy Expenditure for walking (60).

Speed mph	Energy expenditure Calories/minute	Calories/foot
1½	2.0	.0151
2	2.5	.0145
2½	3.2	.0143
3	3.9	.0145
3½	4.8	.0155
4	5.9	.0172
4½	7.5	.0192
5	9.8	.0223

It is reasonable to postulate that the most efficient pace, in this case that with the lowest energy consumption per foot, differs between individuals. It is related to the natural period of oscillation of the leg, more energy being required to obtain frequencies that are above or below the natural frequency. The raising of the center of gravity of the body is also a factor; this increases from a total of about 9 feet per minute at 2½ mph to 25 feet a minute at 5 mph. This may account for about 15% of the total energy expenditure.

An interesting analysis was made of the use of power in running (22) with an overall efficiency of 22.6 percent. The human input was 29 liters of oxygen per minute (equivalent to 29 x 0.48* = 13.92 hp). The output was distributed as follows:

	hp	percent
Kinetic energy in legs and arms	1.67	57
Deceleration of limbs	0.67	23
Work against gravity	0.10	3
Wind resistance	0.13	4
Friction of foot with ground	0.37	13
	2.94	100

A high proportion of the energy is used to move and brake the limbs. A significant part of this could be saved if the limbs are moving at natural frequency. It should be added that this runner was a trained athlete who would be likely to have a greater capacity and efficiency than an untrained man.

Efficiency is also related to the portion of the body moved in performing the task. If the worker is able to perform the task seated, the energy expenditure is about 0.3 Cal/min lower than if standing. Using the lowest order of movement as recommended by Barnes in the principles of motion economy(3) has a sound work physiological basis. The use of the arm, if the job could be done by hand motion alone adds considerably to the rate of energy expenditure (Table 8.)

The mechanical balance of the load on the body may also affect the efficiency. In carrying loads, for example, the most efficient method is generally to carry an equal weight hanging from each hand. Carrying the whole load hanging from one hand - - when it is possible - - increases the energy expenditure by about 15 percent. This is usually explained by the considerable "static work" necessary to maintain posture against this unbalanced load. In a similar way, if the load cannot be divided and is carried on the back, the energy expenditure is about 10 percent greater than carrying a similar weight equally divided between the hands.

Carrying the load on the hip introduces considerable unbalance and increases the energy expenditure by about 10 percent compared with carrying a similiar load on the back (18, 60).

Table 8. Limb Activity and Energy Expenditure (60).

Limb activity	Energy expenditure, range, Cal/min above resting*	
Work with hands	light	0.3-0.6
	medium	0.6-0.9
	heavy	0.9-1.2
Work with one arm	light	0.7-1.2
	medium	1.2-1.7
	heavy	1.7-2.2
Work with both arms	light	1.5-2.0
	medium	2.0-2.5
	heavy	2.5-3.0
Work with the body	light	2.5-4.0
	medium	4.0-6.0
	heavy	6.0-8.5
	very heavy	8.5-11.5

* For normal-sized man: sitting posture add 1.5 Cal/min to above values for posture and resting energy expenditure, standing but stooped add 2.0 Cal/min; standing add 1.8 Cal/min.

Note: This table can be used for the prediction of energy expenditure when specific values for the task are not known.

FATIGUE

Fatigue is a term used to denote inability of the body to maintain a physiological or psychological equilibrium. With the relatively low level of energy expenditure observed in industry today, physiological fatigue is probably not so serious as boredom in its effect upon human efficiency. However, its importance has been recognized for many years, and it is the subject of one of the earlier books by the Gilbreths (25). This book has a subtitle: "The Elimination of Humanity's Greatest Unnecessary Waste - - A First Step in Motion Study." This is how the Gilbreths describe fatigue.

It is possible to detect physiological fatigue by a gradual and continued build-up of the heart rate and in an increase in the "pulse debt" (Figure 3). Brouha has used the oral temperature together with pulse debt to indicate fatigue (8).

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* One liter of oxygen per minute is taken as equivalent to 0.48 hp input.

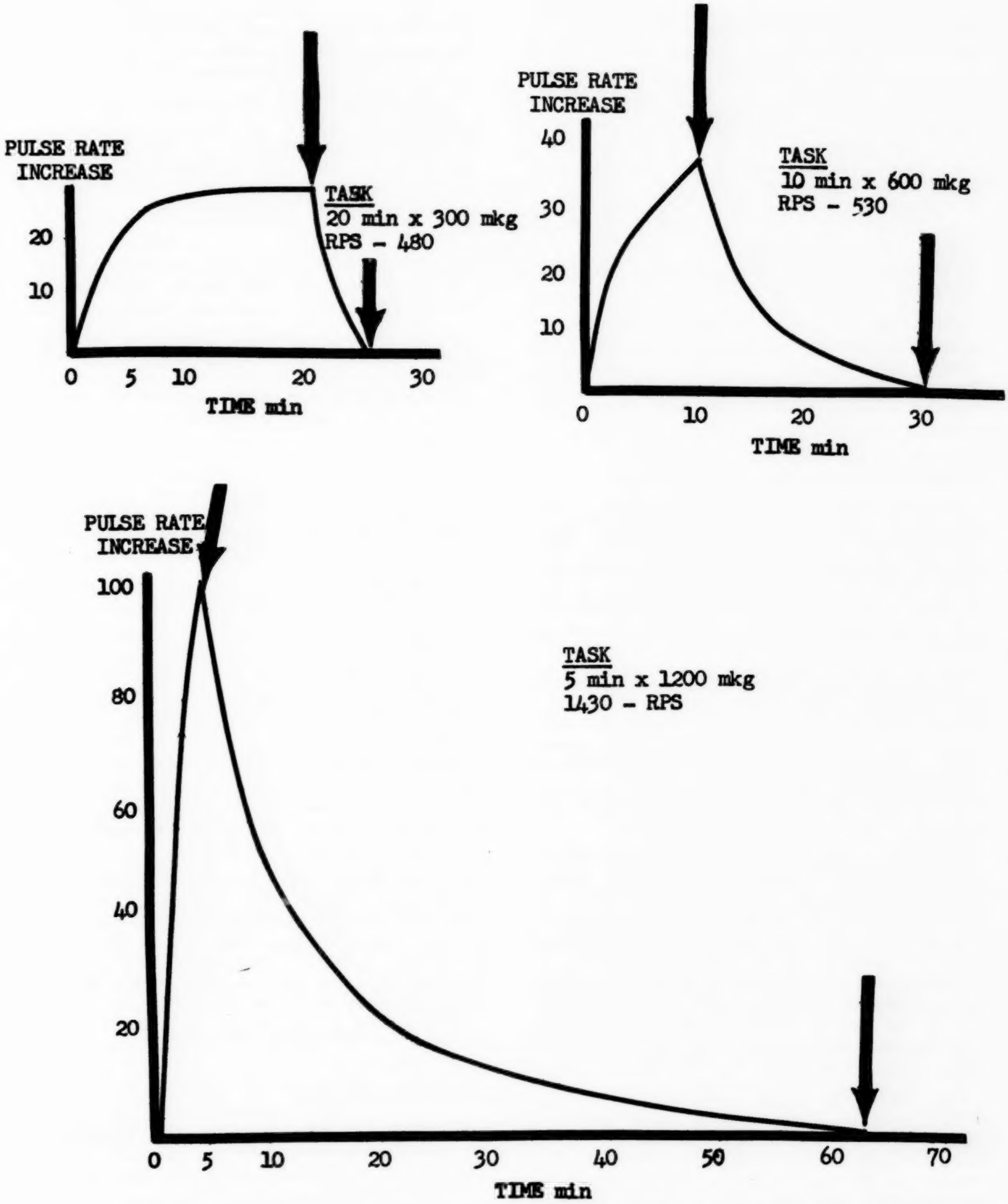

Fig. 3 Recovery Pulse After Performing the Same Quantity of Work at Three Different Rates (Müller, 47)
(Arrows denote the beginning and end of recovery)

Physiological fatigue may also be accompanied by a depletion of the carbohydrate reserves, which can be shown by the blood sugar concentration; an increase in lactic acid content of the blood and the building of an oxygen debt; and dehydration from heavy sweating.

It has been reported that the motion pattern becomes less accurately repeated and that the pattern as traced by a chronocyclegraph demonstrates this (36). However, other studies have failed to find such changes in athletes, even near the limit of human performance. It is suspected that in performing certain tasks traces of irregularity from fatigue can be detected in the readings from the force platform.
the frequency at which apparent fusion of the flicker into a continuous light is reported.

The energy expenditure is expected to rise with true muscular fatigue; other muscle groups are presumably brought into play when the initial groups involved become fatigued. Zuntz (75) reports a 23 percent increase in energy expenditure per minute after four hours cycling at the moderate pace of 10 mph.

UTILIZATION OF THIS APPROACH BY INDUSTRIAL ENGINEERS

Industrial engineers have in the last quarter century concentrated upon one component of the human input, time and neglected the second, the rate function. Economically in industry today there is some justification for this, since we have no model for the cost of the rate of input or the rate of energy expenditure, while the cost of the time component is relatively simple to estimate.

Physiological factors are built into the principles of motion economy and are also being employed to a limited extent in human engineering. However, human engineering is greatly dominated by applied experimental psychology and includes only a little work physiology. For example, in a recent text book-on human engineering no material on physiology of work was included.

As has been mentioned earlier, physiological principles were used in the studies by Taylor. Well known work physioligical studies include the reduction of heat stress carried out by Brouha for the Aluminum Company of Canada (10) and heat and work stresses in Swedish steel mills by E. H. Christensson (13). A comprehensive study of the cardiac at work in industry has been made by Hellerstein and Ford (30). Perhaps I should add the work of my own team in agriculture (45). Extensive studies have been made of the activities of service personnel (15,.50, 70).

Data are available on the performance of some individual tasks. The compilations by Spitzer and Hettinger (59, 60) and of Passmore and Durnin (50) are of particular note. A series of four leaflets on the effective use of human energy has been prepared by the Loss Prevention Department of Liberty Mutual Insurance Company (42). Moving of packing cases by stevedores and laying of paving stones has been studied by F. H. Bonjer in Holland (6). Studies by Muller have resulted in the design of a wheelbarrow requiring 20-30 percent less energy expenditure from the worker (18). Lehmann and others have also reported studies of industrial work of forging and various tasks in the manufacture of automobiles (41, 57).

The optimum location for suspended tools, such as pneumatic screw-drivers and wrenches, in relation to the position of the worker has been studied physiologically in the Graduate School of Public Health at Pittsburgh. Apparently the position in which the greatest force can be exerted coincides with that of the lowest energy expenditure.

Several studies have been made on vehicular seating (16, 29, 51, 58). These have led to the design of improved seats for tractors and truck drivers.

A new branch of medicine, together with its physiological components, is being developed for the conquest of space. Here again past and future research in physiology will aid the space engineer in the design and equipment of space capsules and the homes of the astronauts to be placed on other planets.

Most of the modern studies mentioned in this paper have been made in Europe, particularly in Germany, Sweden, and England. In the U.S. research in the area of work physiology seems to be centered in the armed services and the farm and industrial cardiac studies.

The physiological approach will show the industrial engineer the physical demands of the job. Knowing this he can estimate "job difficulty" and develop changes where necessary to reduce the demands; these changes may be in the work method, the tools, or the environment. The industrial engineer can also objectively predict or estimate necessary rest pauses to minimize fatigue and health hazards.

Knowledge in this area will also assist the industrial engineer in job placement. For example, body weight is correlated with susceptibility to heat injury (61); therefore, where the heat stress is inevitably high, overweight workers should not be used.

The next 20 years will place greater demands upon the ingenuity of the industrial engineer than the last 50. Here for example is the challenge to study the whole function of human efficiency using objective tools to fit the job better to the worker, and in the case of space engineering, even to make the job possible for the worker.

I will watch with interest your response.

1. ADOLPH, E. F., *Physiology of Man in the Desert,* N. Y. Interscience, 1947.
2. BALKE, E., et al, Work Capacity after Blood Donation, Journal Applied Physiology 7 (3) 231-238, 1954.
3. BARNES, R. M., *Motion and Time Study,* Wiley, New York, 3rd Edition, 192-312, 1949.

4. BELDING, H. S. and HATCH, T. F., Index for Evaluating Heat Stress in Terms of Resulting Physiological Strains, Heating, Piping and Air Conditioning, 27 (8) 129-136, 1955.
5. BENEDICT, F. G. and MURSCHHAUSER, A., Energy Transformation during Horizontal Walking, Carnegie Institute, Washington Publication 231, 1915.
6. BONJER, F. H., The Effects of Aptitude, Fitness, Physical Working Capacity, Skill and Motivation on the Amount and Quality of Work, Ergonomics 2 (3) 254-261, 1959.
7. BREZINA, E. and KOLMER, W., Uber den Energienverbauch bei Geharbeit unter dem Einfluss verschiedene Geschwindigkeit und Belastungen, Biochem. 2 (38) 129, 1912.
8. BROUHA, L., Fatigue — Measurement and Reduction, S. A. M. Proceedings, August, 1953 and Industrial Medicine and Surgery 22 (12) 547-554, 1953.
9. BROUHA, L., The Lauru Force Platform, *in* Rosenbaum, F. F. and Belknap, E. L., *Work and the Heart,* New York, Hoeber 1959, 196-198.
10. BROUHA, L. and BALL, M. V., Research on Industrial Fatigue, Revue Canad. de Biologie 7 (3) 479-483, 1948.
11. BRUCE, R. A., Private Communication, University of Washington, Medical School, Seattle, 1956.
12. BURGER, G. C. E. and HARTEN, G. A., Pulse Rate and Blood Pressure during Work (preliminary) N. V. Phillips, Gloeilampenfabrieken, Eindhofen, Netherlands, April 1956.
13. CHRISTENSEN, E. H., Physiological Evaluation of Work in Nykroppa Iron Work *in Fatigue* ed Welford, A. T., and Floyd, W. F., London, H. K., Lewis, 1953.
14. CONSOLAZIO, C. F., JOHNSON, R. E. AND MAREK, E., *Metabolic Methods,* Mosby, St. Louis, 1951.
15. CONSOLAZIO, C. F., JOHNSON, R. E., AND PECORA, L. J., Physiological Measurements for Use in the Study of Metabolic Functions, U. S. Army Medical Research and Nutrition Laboratory (Denver) Report 239, 1959.
16. DIECKMANN, D., Einfluss vertikaler mechanischer Schwingungen auf den Menschen, International Z. angew. Physiol. einschl. Arbeitsphysiol. 16, 519-564, 1957.
17. DILL, D. B., Regulation of the Heart Rate *in* Rosenbaum, F. F., and Belknap, E. L., *Work and the Heart,* New York, Hoeber 1959, p. 60.
18. DRESSEL, G. KARRASCH, K. and SPITZER, H., Investigation of the Work Physiology of Shoveling, Carrying Concrete Blocks and Using a Wheelbarrow, Translated by Purdue Farm Cardiac Project from Zentralblatt fur Arbeitswissenschaft und soziale Betrielspraxis 8 (3) 33-48,. 1954.
19. DUNER, H., Oxygen Uptake and Working Capacity in Man during Work on the Bicycle Ergometer with One or Both Legs, Acta. Physiol Scand. 46:55-61, 1959.
20. DURNIN, J.V.G.A. and EDWARDS, R. G., Pulmonary Ventilation as an index of Energy Expenditure, Quarterly Journal of Experimental Physiology 40, 370-377, 1955.
21. DUPUIS, H., PREUSCHEN, R., and SCHULTE, B., Zweckmassige Gestaltung des Schlepperfuhrersstandes, Schr. Landerbeit und Technik, heft 20, Bad Kreuznach, 1955.
22. FENN, W. O. and MORRISON, C. A., Frictional and Kinetic Factors in Work of Sprint Running, American Journal of Physiology, 92:-583, 1930.
23. FENN, W. O., Mechanical Energy Expenditure in Sprint Running as Measured by Moving Pictures, American Journal of Physiology 90, 343, 1929.
24. FORD, A. B., Application of Energy Expenditure Studies, (Discussion), *in* Proceedings of Purdue Farm Cardiac Seminar 1958, Purdue Agricultural Experiment Station, 1959.
25. GARRY, R. C., et al, Expenditure of Energy and Consumption of Food by Miners and Clarks, Fife, Scotland, 1952; British Medical Research Council Special Report, 289, London, HMSO, 1956.
26. GILBRETH, F. B. and L. M., *Fatigue Study,* Mac Millan, New York, 1919.
27. GREENE, J. H., and MORRIS, W. H. M., The Design of a Force Platform for Work Measurement, Journal of Industrial Engineering 10 (4) 312-317, 1959.
28. GREENE, J. H., and MORRIS, W. H. M., Evaluation of the Force Platform *in* Proceedings of Purdue Farm Cardiac Seminar, 1958, Purdue Agricultural Experiment Station, 1959.
29. HAACK, M., Human Tolerance to Vibrations Occurring in Tractors and Agricultural Machinery, A.S.A.E. Paper Chicago 1955; similar in S.A.E. Trans. 63 452-469 (1955).
30. HELLERSTEIN, H. K. and FORD, A. B., Energy Expenditure by Cardiac and Noncardiac Factory Workers, *in* Rosenbaum, F. F. and Belknap, E. L. *Work and the Heart,* New York, Hoeber, 1959, 122-131.
31. JOHANSSON, J. E., Untersuchung uber die Kohelensaure abgabe bei Muskeltatigkeit, Skand. Arch. Physiol. 11, 273, 1901.
32. KNOWLES, E., Some Effects of the Height of Ironing Surface on the Worker, Cornell Agricultural Experiment Station Bulletin 833, 1946.
33. KUBICEK, W. G. and KOTTKE, F. J., Unpublished Report, University of Minnesota Medical School, Department of Physical Medicine, 1958.

34. LAURU, L., Measurement of Fatigue, Part 1, The Manager, London 22 (5) 299, 1954.

35. LEHMANN, G., Praktische Arbeitsphysiologie, Stuttgart, Thieme, 1953.

36. LEHMANN, G., ibid., p. 42-43.

37. LEHMANN, G., ibid., p. 132, 135.

38. LEHMANN, G., ibid., p. 159.

39. LEHMANN, G., ibid., p. 181.

40. LEHMANN, G., Physiological Basis of Tractor Design, Ergonomies 1 (3) 197-206, 1958.

41. LEHMANN, G., Physiological Measurements as a Basis of Work Organization in Industry, Ergonomics 1 (4) 328-344, 1958.

42. LIBERTY MUTUAL INSURANCE CO., Loss Prevention Department, Safety and Production Data Sheets 65, 66, 67 and 67a.

43. LUNDGREN, N. P. V., The Practical Use of Physiological Research Methods in Work Study, Swedish Forest Research Institute, Operational Efficiency Report 6, 1959.

44. McARDLE, B. W., et al, The Prediction of the Physiological Effects of Warm and Hot Environments, Med. Res. Council, London, Report No. 47/391.

45. MORRIS, W. H. M., Editor, Proceedings of the Purdue Farm Cardiac Seminar 1958, Purdue Agricultural Experiment Station 1959, 90 pp.

46. MORRIS, W. H. M., The Application of Energy Requirement Data in Estimating the Work Load of Farmers, *in* Proceedings Farm Cardiac Seminar, 1958, Purdue Agricultural Experiment Station, 1959.

47. MULLER, E. A., The Physiological Basis of Rest Pauses in Heavy Work, Quarterly Journal of Experimental Physiology 38: 205-215, 1953.

48. MULLER, E. A. and HIMMELMANN, W., Gerate zer kontinuerlichen fotoelektrischen Pulszahlung, Arbeitsphysiologie 16: 400-408, 1957.

49. NADLER, G., *Motion and Time Study,* New York, McGraw-Hill, 1955, p. 417 et. seq.

50. PASSMORE, R. and DURNIN, J. V. G. A., Human Energy Expenditure, Physiol. Rev. 35 (4) 801-840, 1955.

51. RADKE, A. O., The Application of Human Engineering Data to Vehicular Seat Design, Bostrom Research Laboratories, Bostrom Manufacturing Co., Milwaukee, 1956.

52. ROBINSON, S., Experimental Studies in Physical Fitness in Relation to Age, Arbeitsphysiol. 10: 251, 1938.

53. ROHMERT, W., Ermittlung von Erholungspausen fur Statische Arbeit des Menschen, Int. z. angew. Physiol. einschl. Arbeitsphysiol. 18: 123-164, 1960.

54. SARNOFF, S. J., et al, Hemodynamic Determinants of Oxygen Consumption of the Heart with special reference to tension-time index, Amer. J. Physiol., 192: 148, 1958.

55. SCHNEIDER, E. C., and KARPOVICH, P. V., *Physiology of Muscular Activity,* Saunders, Philadelphia, 3rd Edition, 1839, p. 160 et. seq.

56. SCHNEIDER, E. C. and KARPOVICH, P. V., ibid p. 64.

57. SCHOLZ, H., Changing Physical Demands of Foundry Workers in the Production of Medium Weight Castings, Ergonomics 1 (1) 30-37, 1958.

58. SIMONS, A. K., Tractor Ride Research S.A.E. Trans., April 1952, 357-364.

59. SPITZER, H., Physiologische Grundlagen fur der Erholungszuchlag bei Schwerarbeit REFA-Nachrichten 2: 37-42, 1951.

60. SPITZER, H. and Th. HETTINGER., Tafeln fur den Kalorienumsatz bei korperlicher Arbeit, Sonderheft der REFA-Nachrichten, 1959.

61. STALLONES, R. C., et al, An Epidemiological Study of Heat Injury in Army Recruits, A.M.A. Arch. Industrial Health, 15: 455-465, 1957.

62. STUDER, F., Der Sauerstoffverbrauch bein Gehen auf Horizontaler Bahn Pflug. Arch. 212: 105, 1926.

63. SUGGS, C. W. and WILSON, R. W., Tobacco Priming (Walking vs. Riding), Department of Agricultural Engineering Information Circular 9, North Carolina State College, Raleigh, 1954.

64. SUGGS, C. W., The Effect of Work Load and Environment on Some Physiological Responses by Man, Ph.D. Thesis, University of North Carolina, Ann Arbor, University Microfilms 59-4696, 1959.

section 23

AN APPRAISAL OF THE STATUS OF RESEARCH ON PRODUCTION SCHEDULING

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Mr. Sisson received the B.S. and M.S. degrees in electrical engineering from the Massachusetts Institute of Technology.

He has had ten years' experience in the design of digital computers, in the management of a customer's service group and in the design of data processing systems.

Before joining Aeronutronic, Mr. Sisson was a partner in the firm of Canning, Sisson & Associates. This firm specialized in the design of data processing systems for commercial applications and many related activities. Prior to this, he worked at the National Cash Register Company where he was Manager of Customer Service.

Earlier he worked on the development of analog digital computer techniques, the design of data reduction systems for missile test range, and on the development of timing equipment for missile firing applications.

Mr. Sisson has written a number of papers concerning the use of data processing systems in commercial applications. He is a member of the Institute of Radio Engineers, the Association for Computing Machinery, the Institute of Management Sciences, the American Mathematical Association, Tau Beta Pi, Sigma Xi and Eta Kappa Nu.

section 24

THE ROLE OF INDUSTRIAL ENGINEERING RESEARCH IN INDUSTRY

by ROGER L. SISSON

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Dr. Brown is a graduate of Purdue University with a B.S. degree in Electrical Engineering. He received his Master's degree in Engineering from Stevens Institute of Technology and his Ph.D. in business administration from New York University.

He started with Western Electric as an assistant engineer at the Kearny (N.J.) Works in 1946. Working up through various engineering assignments at Kearny and at the Merrimack Valley Works, in Massachusetts, he became an assistant superintendent in the Engineer of Manufacture organization at Kearny in 1955. Two years later he became the first head of the New York Center of the Company's Graduate Engineering Training Program, one of three full-time study centers established by the Company in cooperation with leading colleges and universities to provide various types of special training for engineering employees. He left that post in the fall of 1957 to take his present position, in which he is responsible for direction of work in integrated data processing, systems engineering and the general areas of operation research and management science.

Dr. Brown has written articles for the Company's technical publications and is a member of the Institute of Radio Engineers, the American Statistical Association, the Institute of Management Sciences and the American Society of Mechanical Engineers. He has also served on special committees of the ASME.

AN APPRAISAL OF WORK MEASUREMENT RESEARCH

by J. M. ALLDERIGE
Professor

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Professor Allderige is a graduate of Yale University with a B.S. degree in Industrial Administration. In 1948 he received his Master's degree in Industrial Engineering from Columbia University.

Professor Allderige has had a noteworthy career in business as well as the academic field. He has served as Project Engineer and Technical Advisor for the Eastman Kodak Company. He is active in many professional and science organizations.

Professor Allderige is the author of many publications in the field of applied mathematics and statistics in Industrial Engineering.

AN APPRAISAL OF WORK MEASUREMENT RESEARCH

by JOHN M. ALLDERIGE

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I. INTRODUCTION

OBJECTIVES

THE TERM "work measurement research" is somewhat misleading suggesting that there is a research activity with that specific label. This is hardly the case. Indeed, the work measurement activity is characterized by having research of pertinence done under a variety of different labels. This doesn't in any sense diminish the importance of the research to people in work measurement or cast a slur on work measurement itself for not doing its own research. Work measurement is by and large an engineering activity concerned with determining the labor content of operations, either existing or new. It is practiced in a variety of organizational situations—industry, public institutions, merchandising, military—where the traditional concentration has been on the "worker" but more recently has been extended to the technical and professional man. The foregoing is offered in lieu of a definition of "work measurement" since that attempt always seems to bog down in endless controversy over the choice of words.

Any appraisal must first portray the target before offering assessments. Accordingly, this report seeks to:

1. Portray what actually *is* going on in Work Measurement research and other work studies, as opposed to what is popularly *thought* to be going on, by examing research efforts under the labels of industrial engineering, operations research, physiology, and the behavioral sciences;
2. In light of this portrayal, indicate development needs, to bring existing Management Science into engineering use, and research needs to resolve currently unresolvable problems arising in the study of the various kinds of work.

This is obviously over-ambitious, but it can at least be considered a start in this appraising direction. Nor is any "negative attitude" intended by such an examination—reviewing practices and concepts in light of modern thinking is a continuing responsibility.

This report is actually a first draft of the AIIE Work Measurement Research Committee's appraisal report. It has no "official" sanction at present and represents the somewhat personal impressions and viewpoints of the Chairman. Moreover, it is a "broad brush" approach to a vastly complex and extensive matter drawing from articles, research reports, the AIIE Work Measurement Symposium*, and informal personal information. This is not a research report on research activity and lacks undoubtedly specific documentation. At this point, time does not permit a more exhaustive treatment. Nonetheless, as an engineering institute's adjunct, there is a distinct responsibility on the part of the Committee to "report back"—to try to carry out Item 2, above, and bring whatever we can into sharp focus for practitioner, educator, and scientist. Our language (as in these preliminary comments) between ourselves may be obscure to others but at the end we must put together some unequivocal statements for the different groups serving our profession. We will hardly be unanimous but we can certainly delineate directions either to implement agreed-on concepts or to resolve disagreements.

GENERAL POINT OF VIEW

We are fortunate enough to have such diverse scientific efforts joining us in research and their activity indicates a basic point of vew. As engineers, we are essentially "doers"—we "make things work"— . . . design, improvement and installation . . ." We are an integrating activity bringing the knowledge of mathematical, physical, operations and behavioral sciences to bear on particular situations in real life. Engineering research, per se, is either development work—setting up the scientific knowledge in "easy-to-take-tablet-form" for wider application—or basic research seeking to understand the engineer's role in his social environment thereby helping improve his effectiveness. Also included in such research in engineering is the probing of the processes of inquiry to improve methods of shop analysis. These are legitimate engineering research areas where engineering itself—*the activity itself*—is the phenomenon in question.

Industrial Engineering *deals* with phenomena, of course (as well as *being* one), of a social, operational and physical nature and understanding these basically is the essential problem of the research scientist. Indeed, "engineering research" concerning the social and methodological aspects of engineering itself is also in the research scientist's camp—largely in the behavioral and mathematical areas. So research of interest to engineers is quite likely to be carried on under a label that is non-engineering and should, indeed, be so encouraged.

Professional societies (such as the AIIE) have, among others, as a reason for being, the acceleration of the exchange of professional information, both within the profession and between the profession and sciences.

Research organizations are one of a society's groups carrying out this acceleration function and are particularly concerned with the resolving of heretofore unresolved engineering problems. This requires problem knowledge as a basis and may require development work to bring existing knowledge into play or discovery of a new knowledge. Whatever it needs, the AIIE Research Organization must act to make appropriate recommendations.

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*Held in Syracuse, N. Y., October, 1958.

THE RESPONSIBILITY OF SCIENTISTS

Scientists serve as one important link to the fund of existing knowledge as well as potential fund of new knowledge. As we expose our problems, they, with their special knowledge, can undoubtedly help confirm and buttress our thinking, help reframe our problem descriptions in light of existing knowledge, suggest resolutions of problems contained in obscured (to engineers) but present knowledge, and become aware of research needs in their own disciplines as pointed up by the problems. It is hoped that this report, in its eventual form, will permit a start on more coordinated attacks on the problems that are of mutual interest.

II. A Brief Review of Research Activity in Work Measurement

A. *INDUSTRIAL ENGINEERING*

1. *Microscopic Time and Motion Analysis*

There is, of course, continued activity in this traditional area of work investigation. The efforts center around better definitions of motions, continued experiments under a variety of conditions to support or change existing elemental time data. Some work is being done on mathematical model building at this level in an attempt to seek optimum deployment of anatomy and in an attempt critical to analyze the so-called "Laws of Motion Economy."

A new characteristic of such investigation, as far as the Industrial Engineer is concerned, is the invasion of the physiological realm (bio-mechanics). Several efforts are now "going beneath the skin," literally, and exploring such physiological aspects as pulse rate, blood pressure, and oxygen consumption. This is often given the popular label of "fatigue" study but it really has the larger aim of identifying characteristics in a work situation that account for the wider unexplained variations from task time predictions based on motion analyses.

2. *Macroscopic Analysis*

a. Rating—This is another traditional area of interest still undergoing scrutiny although less extensively. Current projects center on examining pooled observations of filmed operations and actual operations both with an eye towards buttressing the rating process itself and towards continued rational critiques of it.

b. Operations Analysis—There is quite a bit of activity in expanding and developing of modern operations analysis techniques. The adaptation of conventional mathematical models to the work situation (linear and non-linear descriptive models), the development of tables for queuing models, the development of techniques for determining sample size and the number of variables to use in describing an operation and the adaptation of various optimizing models (calculus, mathematical programming) to work situations are all part of the picture. Moreover, there are continued efforts to seek characteristic "time study" distributions as well as experiments seeking to compare different shop work measurement processes (work sampling in particular).

c. Job Design—There is activity by Industrial Engineers in an aggregate approach to the work problem—job design experiments are more and more prevalent. These generally try different methods of performing an operation, or series of operations, and observe productivity results. For instance, one such experiment series tried highly specialized tasks by numerous people versus complete assembly by one person with each condition run for several months. Sometimes the terms "work simplification" and "job enlargement" are associated with job design research although they are popular labels attached to extreme conditions still being studied.

d. The Professional Worker—Industrial Engineers are considering the labor content problem in non-"blue collar" areas. The activity is slight but applications of work sampling and the development of special measurement approaches mark at least a beginning of interest and purposeful research activity.

3. *Instrumentation*

Aside from instrumentation for research purposes (a matter outside the interest of this report since it is all part of the research itself), there is continued activity in the development of instrumentation for shop study. Various devices have been and are being worked on to make the collection of data at the operation more rapid, more extensive, and more refined. Extensive use of punched paper tapes, punched cards, and electronic data processing of both a generalized and specialized nature characterize these efforts. Actual shop use has been limited but is probably going to expand.

B. *OPERATIONS RESEARCH AND MANAGEMENT SCIENCE*

1. *Operations Analysis*

Research work of interest to those in work measurement carried out by people operating under the above labels falls into two broad categories: operations and behavioral. The latter is dealt with under item C. below, primarily. Whereas the characteristic Industrial Engineering activity in operations analysis is development of techniques based on research, the operations research and management science people are working on new approaches and new models of future usefulness. Queuing theory refinements, experimental design refinements particularly with respect to process experiments, and basic decision theory all have bearing on work measurement. Mathematical work on numerical analysis along with computer refinements are aimed at making more tractable certain models that have been outside the range of possibility for engineers in day-to-day practice.

2. *The Professional Worker*

Some worth-while attention is being paid to the engineering process itself by Operations Research people. The effort treats this process with the models and simulators so familiar in manufacturing process studies. The high variability and complexity of the engineering process call for some fairly sophisticated treatment and it can only be called primitive at this point.

C. *BEHAVIORAL SCIENTISTS*

1. *General*

There are many disciplines associated with label-psychology, social-psychology, sociology, psychiatry, and certain segments of management science. The research work is extensive but can be broadly grouped into two categories: study of the individual, study of groups.

2. *Study of the Individual*

a. The Rational Individual—This is a controversial heading, no doubt but it attempts to describe work of a psycho-physiological nature on reaction times, color and shape response, calculating times, etc. Such work often comes under the heading "human engineering." Intensive military research efforts along this line are taking place as they become more and more involved in intimate man-machine systems.

There is continued activity in testing and examining, of course. Psychological testing has extended to practically all occupations and, interestingly enough, appears to be creating more research the more extensive its application. The changing nature of occupations accounts for much of this—workers as monitors of complex automatic equipment represent something quite different from the familiar free-effort operation. In this same connection, psychological study of the learning process must be noted. Industrial Engineers are working on the matter as well, as should have been stated above.

b. The Emotional Individual—Reaction times, color response, and the like are one thing—the emotional set of the individual can affect behavior along these lines and experimental research work aimed at disclosing the emotional component is more and more apparent. These experiments are generally in limited and controlled "laboratory" situations. Most research work in the real life setting (limited as it is) tends to be more observational, or clinical than experimental (as far as *individual* study is concerned—group experimental work is noted below). The major exception, of course, is the military where there have been numerous experiments of actual man-machine systems to explore emotional response and stability.

Psychoanalytic concepts are being introduced anew in the study of the professional man and, particularly, the manager. Here, the research work seeks to demonstrate the effect on managerial leadership, motivation, and control of a manager's unconscious mental processes. It hypothesizes that as conscious control and awareness of these are increased, managerial effectiveness will tend to be increased.

3. *Study of Groups.*

a. Industrial Studies — This is a classical area for psychologists and social-psychologists. The Hawthorne experiment is long over but it has several more recent counterparts (in basic idea — not result). The job design experiment mentioned earlier is typical of current experimental work — other kinds of situations are explored also. Comparisons of different goal-setting techniques are typical — several experimental series have examined autocratic-unilateral, bilateral, and group productivity goal-setting in reasonably faithful real-life settings. Questionnaires, depth-interviewing, and clinical observation have been used in follow-up. And it is worth noting that only limited clinical observation work is being done in this area.

Another research activity of note here is that of the critical scholar. Work Measurement has had several in recent years not only dealing with technical matters but particularly dealing with behavioral matters relating to worker groups in the industrial situation. Scholarly critiques are quite familiar on the sociological scene ranging from the esoteric to the best-selling popular kind. This may not be considered research by some but its impact is considerable.

b. Laboratory Studies—Group studies are being conducted "inside" more and more in an attempt to come to grips with basic ideas. The term "Group Dynamics" is often used in connection with such experiments. Experiments of this kind set up primitive to complex group tasks and pursue them in various ways. The individual interactions, the group performance, attitudes, communications, etc. are all subject to scrutiny by the social psychologists. The military has an obvious interest and is active in such work.

The above is just "once-over-lightly" and is no doubt quite incomplete and possibly incorrect in certain places. It is hoped, however, that a general impression is registered—that a picture emerges of many activities pursuing matters that range from the familiar with obvious connection to Work Measurement as generally understood—to the unfamiliar with only a vague connection apparent. This is indeed the picture—a lot of work is going on by diverse interests and it all has bearing on Work Measurement as we Industrial Engineers intuitively know it.

III. *Commeht on Research Directions*

A. *GENERAL*

It's interesting to see the several main streams of thought that are in evidence in most of the research. In the traditional micro-element time area of Industrial Engineering there has been a slow progression towards physiological research which, in turn, is tending towards the inclusion of more psychology (human engineering). Here there appears to be a legitimate split—there are continued efforts in the purely psychological direction with more and more emphasis on the emotional content and then there are the group efforts in group dynamics and social psychology, moving outwards again to macro levels. It is here that the scientists meet another traditional Industrial Engineering interest, incentive standards, and meets a newer activity of modern operations analysis. So there's a full circle image of this research work.

The following comments range far and wide but start on familiar Industrial Engineering ground. The whole problem of "standards" and synthetic times is first discussed followed by some remarks regarding behaviorial research. The last two short sections touch on operations analysis and engineering design in Industrial Engineering.

B. *THE "ONE NUMBER" IDEA*

Standards

The fundamental point of view reflected in most thinking might be called the "one number" idea. This says that there exists for any described performance of an operation one "right" time value. Given this premise the problem, then, is one of finding that number. This number is conventionally called a "standard" or a "normal time" or a "fair day's work time." With that somewhat general notion, the process of finding that number follows two paths. On one hand there is an impression—a concept—of what this normal time value is and it is felt that if enough impressions are pooled this might operate as a definition of the normal time. On the other hand, however, there is the constant question, "Does it work?"; is the actual performance "reasonably close"? So there appears to be another basis for evaluating "normality." Now, it is not really important from a theoretical point of view whether or not these two definitions conflict. It is, rather, important to note that there are two. Of course, in practice they do often conflict—many grievances are testimonials to this fact. But the important thing, again, is that there *are* two and in the seeking of a "standard" this has to be resolved.

Operational Definitions

Still staying with this one number idea and accepting it for the moment as appropriate, one might seek to resolve the above dilemma by establishing an operational definition of a standard. Using the first notion—the notion of the pooled concepts—one might say that a "standard" is what the pooled opinion of a specified number of observers say it is. These observers would, of course, all be tested for consistency through a variety of devices well documented in the literature on sensory perception—taste-testing, print inspection, etc. Now, this has been done under the idealistic situation of movies in which the identical operation cycle is repeated and numerous operations observed. The results universally have shown that the distribution of individual rating instances have a two standard deviations value of plus-or-minus 15 to 20% of the mean. Moreover, studies show that the major component in variance is within-observer variance—the apparent inability of an observer to reproduce his value judgment under presumably identical situations. Let us note, somewhat parenthetically, that if this appears as a surprise, it is, perhaps, due to the fact that most published reports on rating deal in averages and not with individual rating instances. None-the-less, with this information of the inherent variability of the observer, certain statistical suggestions can be made, such as pooling observer opinion in the actual rating instances on the job and getting sufficient population of observers to give some confidence interval on the average value.

The above very sketchily demonstrates that it is within our statistical ability to develop some universal standard for any described operation—a universal standard, of course, based upon the above operational definition. This would be a delicate job requiring a lot of fairly high-powered statistics that are, perforce, associated with psychophysical measurement of this sort. But let's put the case that was done and, for the moment, forget other problems that will be mentioned later regarding the synthesis of elemental operations or movements—so what? There still is nagging at the back of our minds the question, "will it work?" This is another way of saying that somehow or other we don't quite accept the impassionate neutrality of a statistically-controlled, highly consistent and precise jury registering "objective" opinions. We cannot desregard the fact that difficulties might arise if this opinion is too far removed from what actually is taking place in some local situation. Accordingly, at the other end of the stick, so to speak, there is another possible operational definition of the normal time. This definition might read, "A standard is what a large group (say more than 20) of trained people (operating on the higher level plateau of the learning curve) will do." Now, this is another definition which one can proceed to verify with statistical techniques and obtain a very consistent figure. There might be several feelings about this type of a standard. If the operator population was fairly universal, the local problem of "will it work?" still prevails. On the other hand, if this definition is sought purely locally, then there is a feeling that perhaps a great chance for improvement is being missed—its very lack of universality makes it suspect.

So, even with refined operationally verifiable definitions, the dilemma still exists. On one hand, we do not quite trust what is observed and on the other hand, we do not quite dare not to trust it. There is probably no debate that this dilemma exists only in the incentive pay situation, for where incentive pay does not prevail and where it is purely a problem of getting time values —not "standards" in the conventional sense—statistically sound work measurement can offer pertinent and valid time values for such purposes as predicting manufacturing costs and scheduling production. In the area of design, the dilemma as described does not prevail for here, again, local data are appropriate inputs. The question there deals with the technical problem of synthesis—how to put even good elemental times together for a reasonable prediction.

The notion of a standard is only important where one is concerned with *improving* performance and not *using* it as it exists. This, at least, is a paraphrase of the conventional thinking. And there is a general realization that a standard improvement expectancy can't be too great without inducing the opposite effect. Thus, discouragement sets in and this is true of all areas of human endeavor. Nor can a standard improvement expectancy be too small for this disrupts the *a priori* notion of wages. In a qualitative sense, perhaps, partial resolution of this dilemma can be achieved if a standard is thought of not as what a group of "experts" say it is, not as people actually perform, *but as what performance will be under some future altered circumstances.* More specifically, in the conventional incentive pay situation two dominant things take place when an incentive pay plan is instituted; (1) the declaration of a standard, and (2) more money. Both of these represent a very major change in the situation as it was measured and the pooled opinion idea appears in reality to be an attempt to predict what will go on under these changed circumstances. We can, in other words, by introducing socio-economic factors, perhaps explain the phenomenon a little better and perhaps improve our notion of a standard. A standard is conventionally thought of, now, as a function of method. This might be called a physiologically based standard (or perhaps anatomically based would be better) and our apparent dilemma over making such a standard satisfactory suggests a standard that is a function of the economic aspects—such as the base earning rate, the money offered, the proposed productivity increase — and the social aspects —mainly the impact on motivation of the declaration of the standard. One gets the impression, currently, that setting a standard is partially creating a standard —something on the order of measuring the temperature of a bucket of water with a hot thermometer. The resulting temperature is dictated to a certain degree (no pun intended) by the initial temperature of the thermometer itself. In a similar fashion the very declaration of the standard to a large degree dictates the eventual performance against that standard. There appears to be a fairly reasonable range within which anything will work, which always suggests something higher *might* have worked and contributes to the feeling that the "will it work" criterion for normality is not entirely acceptable, at least in a theoretical sense.

Of course, in the practical sense, the "will it work" criterion is the only usable one, by definition. And if, as suggested above, there's a wide range of workability, the thought naturally arises, "Why not *use* some universal 'one number' system?" Again, practically, synthetic systems are more complex than is usually needed for the local situation. They have to be, of course, to be universal but this unwieldiness defeats their ostensible purpose. Far greater engineering economy can be realized by intelligent local operations analysis using up to date statistical and mathematical tools than can ever be done using synthetic systems. For the day of highly repetitive elemental motions is waning. Element mix and product mix dominate and good *use* of even poor data is better than poor use of *good* data (if one were to admit for the moment that universal data *were* good). There's a blending problem in synthesis that still has to be met and which is as hard as getting the numbers to blend. Universal synthetic systems are inadequate on technical grounds in a large number of operations today. They mistake refinement for insight and do not embrace a notion of the decision that is to be made with the data.

Now, on a theoretical basis, the "will it work" criterion is usually invoked when the standard *doesn't* work. Yet it is really most suspect when it *does* work since there is the good chance that some *other* standard might have been fairer. The working standard *is* fair since it *is* working—again, by definiton. But maybe a higher or lower standard would *also* have worked with the attendant lower and higher money return (the desirability of direction—of what is fairer—of course, depends on the operating philosophy of productivity *vis-a-vis* purchasing power). Accordingly, if we seek this "one number" (really "one best" number) we must recognize that a standard is dependent not only on method but on the social and economic factors involved, as well (at least). Of course, unquestionably psychological factors are involved. However, these factors relate to the individual and the incentive system is presumably designed to discriminate between individuals on the basis of productivity regardless of their particular emotional or even physiological variability. So, if these social and economic factors are appropriate and one can envision a standard as a three-way function of the method, social situation, and the economic situation, it follows that we need descriptions of these social and economic conditions. It means that socio-economic measures are, in part, fundamental to implementing the "one number" idea. Quite frankly, it's hard to comment on the adequacies of current sociometrics to meet this need. It seems that the disparity between base rate and proposed monetary return considered along with the proposed productivity increase, considered along with the social status of the individual or individuals involved which would give some clue as to earning aspiration, are broadly the factors that need be measured. It is the latter social factor which one suspects is difficult and that perhaps we should discuss at some length with people in that discipline.

In the event, as is most likely, this is fairly virgin territory, it would seem that the "one number" idea is inadmissable at our current level of knowledge. It does not seem likely that the next decade, even, could produce sufficiently competent, sufficiently adequate social measures let alone a usable formulation of this group motivation system for such a "one number" standard. It is *not* that it should not be pursued — indeed, this is the alternative proposal that is put forth —but it does seem to leave us in the position of developing local standards with industrial engineers more competent in their local operations analysis. This is also offered as an alternative research direction.

The fundamental point of view—the "one number" idea—does not appear to be theoretically acceptable currently since the factors necessary for adequately describing such a standard are not all measurable. Moreover, the residual chance variability that exists when one considers only method and not the social and economic factors does not necessarily produce a workable standard and cannot produce except by accident an optimum standard in the local context.

C. THE CLINICAL APPROACH

One point worth pursuing was only hinted at above. It was noted how important socio-economic measures appear to be in the development of a "standard" concept. Now, it may be that the need for this concept is no longer with us (or, at least, is disappearing) but it might be well to dwell on a possible method for such development with an eye towards using it for other investigations, particularly of the professional man. It has been the general experience of experimental work in the area of motivation that much is not known, that experiments are limited in scope by their very nature particularly with respect to the emotional aspect. The reproduction of real life just isn't realized, moreover, the necessary limited duration of an experiment (such as the job design experiments) raises a question as to what is really trying to be proved. Put the case that there is a definite result that can be repeated with respect to, for example, group set goals. But say that this produces higher productivity over a three-month span. What can be said for a one year span or a life-time span? How close can we come to uncovering basic characteristics of the human in the work situation without considering life as a whole?

Now this may seem to be so large a question as to be absurd. But there is one possible method of such investigation particularly if it is limited to the industrial scene. The clinical observational approach is the one in mind. This entails, generally, observing the phenomenon in natural surroundings much as is done with the weather and in astronomy. It admits that laboratory examination is unsatisfactory and goes to wide scale observation with the construction of progressively improved predictive models of the phenomenon. Considering the large number of Industrial Engineers in active observation throughout the industrial world, it seems like not an impossible idea to train a limited number of competent ones in observational techniques and pull together such observations. Social-psychologists and scientists with like interests could then postulate models based on such observations (after having designed observational requirements in the first place, of course) and feed back recommendations for changed patterns of observation. The observation itself would consist of such gross information as estimated socio-economic measures, actual productivity, wage levels, and the like. The matter can be expanded considerably but the above is the general idea. It all comes down to a group of sociological "weather" stations which, if wide-enough spread, can, with simple but reliable information, offer a major break-through in macro-group understanding.

D. OPERATIONS ANALYSIS

A considerable amount of work is being done these days under the labels of "Operations Research" and "Management Science" that deals with techniques for solving operations problems. Only a dribble is getting to the Industrial Engineer. There is a tremendous need for development work and this is a particular responsibility of the Industrial Engineering profession. There should be a massive outpouring of manuals, work-books, interpretive and expository writing, and training courses all aimed at up-dating the practicing engineer. Since much of the Industrial Engineering activity is in Work Measurement, there is a major need to give it the labor content slant. Not only can these techniques vastly improve the basic business of determining labor content and controlling it but they can be the vehicle for keeping the Industrial Engineer in business. This may sound like a cry of doom but it is a very grave reality. Moreover, it may not sound like research but it takes good, hard development work to generalize on techniques and make sure they can be universally adapted to a class of problems. Other professions and sciences are turning their best talent to such tasks (physics, chemistry, mathematics) and we certainly can do no less.

E. ENGINEERING DESIGN

The state of engineering design in Industrial Engineering is at a low ebb relative to other aspects of the profession. By this is meant the designing of an operation, the designing of a process, and the designing of a plant. Certain integrative techniques have been very helpful in designing control systems and, more practically, in just solving local one-shot problems. From a work measurement point of view, it can hardly be said that given the specifications of an operation (or the end requirements) there is a rational method of sifting through all the endless possibilities and producing *the* design that maximizes some objective. That this is a tall order is not questioned—that little is being done to work on the problem is also not questioned, although some may complain.

The psychologists aren't particularly helpful in this since they generally don't have mathematical concepts well in mind and are more concerned with discovering "basics" than developing a useful engineering methodology based on model building. The traditional areas of Industrial Engineering offer check lists and nothing else—the real answer lies someplace between the search for "basics" and the offering of check-lists coupled with an almost institutionalized "questioning attitude".

What is needed for operations of a local nature is a set of reasonable data (and some of the micro-element systems consolidations start to get close to this) coupled with good methods of testing and modifying. The latter requires techniques of model building that particularly take into account the needs of the system as a whole. In other words, too often an operation is designed "to pieces" which puts it completely out of phase with the rest of the process in which it's embedded. Some theoretical work must also be done on the putting together of such data, on the manner whereby an engineer can sort out rationally many possibilities and move to a good combination. It isn't enough to have reasonable data for various elements—there must be a way, besides cut and try (or simulation, more elegantly) to put the best, or thereabouts, combination together.

IV. SUMMARY

This has been long and rambling and undoubtedly unsatisfactory to many with particular interests in the research activities associated with work measurement. As noted at the outset, it does represent strictly personal impressions and opinions. One impression, however, that cannot be called unique to this writer is the need for increased Industrial Engineering activity in or about research areas. Quite a lot is going on that affects us and we seem to be progressively more unaware of this. We staked out quite an area in our early days and there's considerable pressure on the part of others to move in. This is all to the good and there's no suggestion of jurisdictional dispute here—we have a definite interpretive and implementing role to play. This can take the form of development work, of purification of techniques, of working with scientists in other disciplines to aid in their investigative efforts, and of informational writing to management and the public. As noted before, this may not be research in the strictest sense but, better than that, it can make sure that more and more research is done by those competent and it can make sure that Industrial Engineers are quite closely associated with such research. This is quite fundamental for we have a larger role of implementation to play. And it can only be well played if these efforts of encouragement, interpretation, and development are fully pursued.

RESEARCH IN THE DESIGN OF CONTROL SYSTEMS

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RESEARCH IN THE DESIGN OF CONTROL SYSTEMS

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I. INTRODUCTION

AS DECISION making continues to increase in complexity, involving far-reaching consequences and potentially large risks, there is a need for more effective management control systems which have the capability of functioning in real time. Management cannot afford to operate on hunch, intuition or guesswork; what is needed is the information and decision criteria which aid managers to predict accurately the consequences of their decisions, to choose correctly among alternative solutions, and to provide rapid and accurate response to variable demands.

There have been prognostications that providing top management with computer-processed information will radically alter the requirements on middle management. (1) However, it is more likely that computers will become necessary adjuncts to management, providing rapid and accurate evaluation and analysis of alternatives. The forerunner of such systems using computer simulation as the basis for rapid interrogation, can be seen in military systems such as the SAGE (2) air defense system.

II. PROBLEMS CONFRONTING MANAGERS OF BUSINESS SYSTEMS

A review of some of the problems facing today's managers reveals the magnitude of the task of conducting effective research in this area. Although the following list does not begin to cover all possible aspects of business systems, it nonetheless includes some of today's more pressing problems.

1. Organizational Considerations
   - Determination of whether management should remain centralized or have further decentralization.
   - Provision for effective communication of information and policies, both upward and downward.
   - Determination of the appropriate number of authority levels in an organization.
   - Establishment of a suitable span of control for supervision.
   - Incorporation of the systems aspect in the organizational structure.
   - Determination of how information should be reported and displayed for decision making.
   - Determining the effect of time lags in information flow on system performance.
2. Designing Integrated-Automated Systems
   - Establishing system requirements and objectives.
   - Resolving conflicts and interdependencies among departments.
   - Providing appropriate flows of material, information, money and other resources.
   - Providing an appropriate response of the system to demands.
   - Determining how the system relates to the environment, competition, and markets.
   - Establishing a basis for analysis and evaluation of alternate system designs.
   - Developing a means for testing system designs prior to installation.
3. Developing Effective Management Controls
   - Need for decision criteria to avoid sub-optimization.
   - Relating planning to operational control.
   - Establishing dynamic measures of system performance.
   - Provision for on-line control via feedback.
   - Allowable deviations from desired performance.
   - Speed of response for corrective action.
   - Use of decision rules for consistent response.
   - Determination of which controls can be automated.

III. STUDYING BUSINESS SYSTEM BEHAVIOR

In providing the means for experimenting with a total business system, a quantitative formulation of the various behavioral characteristics, component interdependencies, system flows, and stochastic functions is needed. The purpose of this formulation is to develop a computer simulation program which can trace the activities of a synthetic system as they change in time. In this way, a large number of variables can be examined simultaneously, without explicit knowledge of their interdependencies. This use of a computer simulation program to generate system behavior is often referred to as Monte Carlo sampling.

It should be pointed out that the model of a business system described here is concerned with a "decision network" rather than an explicit characterization of the decision maker per se. The difference stems from studying the information flow and decision rules in the system, as contrasted with studying the behavior of the individual decision maker. To the extent that a model faithfully characterizes the behavior of a given business and that suitable decision criteria can be established, a computer model can generate information useful in the study of business problems such as previously indicated. Further, the computer is capable of providing summaries of the information generated during the simulation to permit evaluation of experimental designs or to permit one to gain useful insights on system behavior.

1. Considerations in Modeling a Business System

When modeling a "total" business system, it is possible to take a number of different approaches. Thus, the model could merely be a symbolic representation of the functions and activities of the business, with little or no attempt to abstract or aggregate the characteristics. A completely mathematical model, on the other hand, might represent too high a degree of abstraction or simplification. It would seem that a combination of the symbolic or logical relationships and mathematical formalizations could provide flexibility, while, at the same time, allowing for succinctness and precision. In any event, the model must be amenable to computer programming so that all relationships must be explicit and quantifiable.

2. Determination of System Objectives

Although considerable energy has been expended in attempts to define the "raison d'etre" of a business, suffice it to say businesses do exist and unquestionably have purposeful objectives. It is through a better undertanding of the behavior and capabilities of the business system that these objectives can be determined with any degree of creditability. It does not seem sufficient to merely accept the pronouncements of desired objectives as the basis for system requirements and design. Hopefully, a satisfactory means for evaluating alternatives, such as computer simulation, could provide the basis for establishing realistic objectives. In any case, it can hardly be argued that the managers of a business are custodians of the resources and as such are responible for the survival of that business. To the extent that these considerations can be formalized, it appears feasible to explore the effect of management decision making and control on the performance of the business system via the computer.

3. Authority-Communications in a Business Model

We might think of the relationship of management to the business resources as shown in Figure 1.

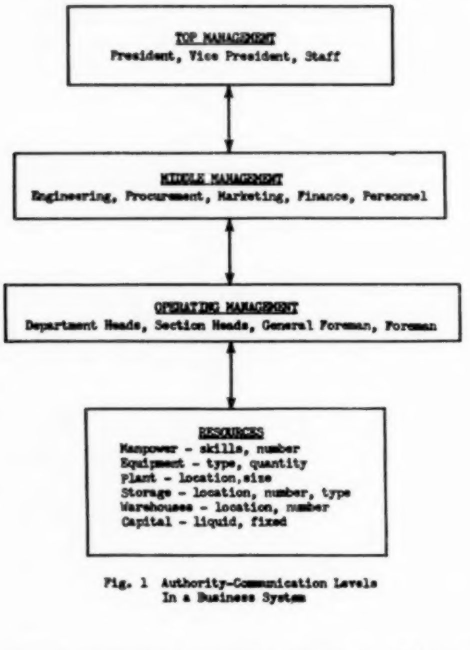

TOP MANAGEMENT
President, Vice President, Staff
MIDDLE MANAGEMENT
Engineering, Procurement, Marketing, Finance, Personnel
OPERATING MANAGEMENT
Department Heads, Section Heads, General Foreman, Foreman
RESOURCES
Manpower - skills, number
Equipment - type, quantity
Plant - location,size
Storage - location, number, type
Warehouses - location, number
Capital - liquid, fixed

Fig. 1 Authority-Communication Levels In a Business System

First, there are various authority levels within the management structure. The implications of the number of such levels on the speed and accuracy of information transmission is an important aspect of any research in management controls. The characteristic behavior of decision makers in response to information would provide a basis for studies concerned with organizational aspects of information flow. The density of communication linkages among decision makers would provide data which could be used to establish the critical decision points in a network. Further, the communication network linking the managers with the operations provides the means for establishing feedback control loops. In a sense, management is linked with the resources of the business via information flowing through a communications network. Characteristics of the information flow among managers and between the managers and the operators would provide one of the basic measures of system behavior. Since information and decisions are normally transmitted serially from the top down, the coupling of management with the resources is inversely proportional to the authority level. Hopefully, computers and proper staff organization can improve this situation.

4. Considerations in Modeling the Decision-Making Function

Looking at the typical activities of top management, one finds that half their time is spent with other managers or subordinates. Of the remaining 50 per cent, approximately half of the time is spent in planning. The remaining 25 per cent is spent in analysis and evaluation of information as the basis for decision making. It is this latter percentage of the manager's activity which may be susceptible to modeling for purposes of computer simulation. Since decision making can hardly be considered unequivocal, the model provides, at best, a crude representation of the actual function. However, an analysis of the points in a system where decisions are made and the informational requirements for the decisions provides a first estimate of the desired communication network. In a real business, much of the information is not pertinent to the direct operation of the business, and often informal communication channels provide useful information. Nevertheless, a study of the precise informational requirements is bound to have an impact on the organizational structure of a business. In a sense, the decision maker has surveillance over a given number of decision points, which, when linked to other decision points, defines the underlying operational structure of the business.

Thus, an organization can be viewed as an information—and decision—processing medium. Management control, on the other hand, requires a consideration of all the factors affecting the operation of a business. From the integrated systems approach, control implies the specification, prediction, and assurance of desired performance. To have predictable system response implies adequate information feedback which provides the basis for corrective action. Looking at the information flow and decision making in current business systems, we find the following:

In Figure 2 it is seen that top management is primarily concerned with decisions affecting the business from a one-to five-year period in the future, whereas

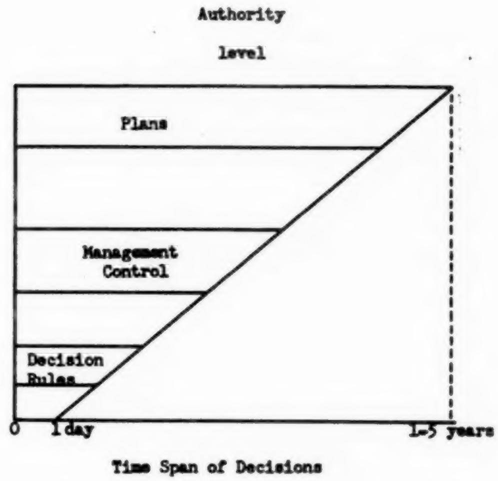


Fig. 2 Multilevel Decision Making

operating management is concerned with the day-to-day decisions needed to keep the business running. From a control viewpoint, the top level of decision making is primarily involved in planning, while middle management is concerned with meeting the plans, that is, management control. Controls at the operating level are primarily of an ongoing nature and could be classed as operating decision rules.

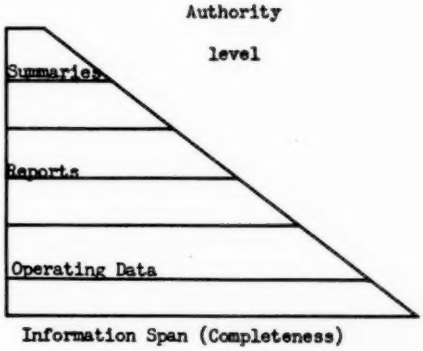


Fig. 3 Informational Aspect of Control

Figure 3 shows that the amount of detail information available to managers reduces rapidly as the authority level increases. Thus, at the top management level, there are various summaries and reports describing the operations of the business system rather than the operating details. It is conceivable that with suitable computing equipment, top management could have more direct access to operating data. However, this would undoubtedly require a shift of some middle management to a staff position, as indicated in Figure 4. Organizational changes, as shown in Figure 4, would be one aspect of a model on decision making that an experimenter could examine.

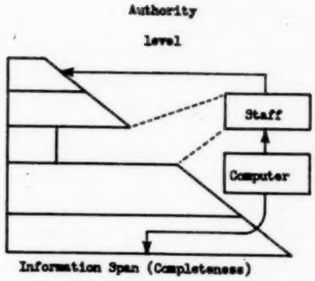


Fig. 4 Application of the Computer to Management Control

IV. MODELING THE ACTIVITIES AND FUNCTIONS OF A BUSINESS SYSTEM

A schematic diagram representing the information flows among various functions and activities in a typical manufacturing (resource transforming) business system is shown in Figure 5. At the heart of the system is the decision-communication network. This is normally thought of as the management function. The decision network, as was shown in Figure 1, is linked to the resource transformation or operations subsystem through the various organizational levels of authority.

To be amenable to computer programming, a model must characterize in symbolic or mathematical form, the various activities, flows, responses, and behavioral characteristics within the operations subsystem. Information on the performance of this subsystem can be presented in the form of displays for use in conjunction with the formalized decision rules. Specific data, reports, or summarizations which measure system performance can also be presented. The model should provide for flexibility in the manner of summarizing information, as well as frequency of reporting and communication links.

Using the simulated information generated in the computer, decisions are carried out in a synthetic manner, which affect the activity of the system. This simulated information can be used to monitor the system activity through the use of alternative management controls. Other inputs to the decision network include the system constraints or policies, system functions, and environmental factors. These, too, would be represented by flows of information via the communication network.

Inputs to the operations subsystem would include environmental factors, customer orders, capital resources, material, etc. In addition, transients or perturbations in the operations subsystem would introduce variability which is not dependent upon the management controls. The outputs of the system enter distribution systems, warehouses, or finished goods storage. Although there is considerable detail associated with the operations subsystem, the modeling need merely treat the information aspects as they interact with the decision network.

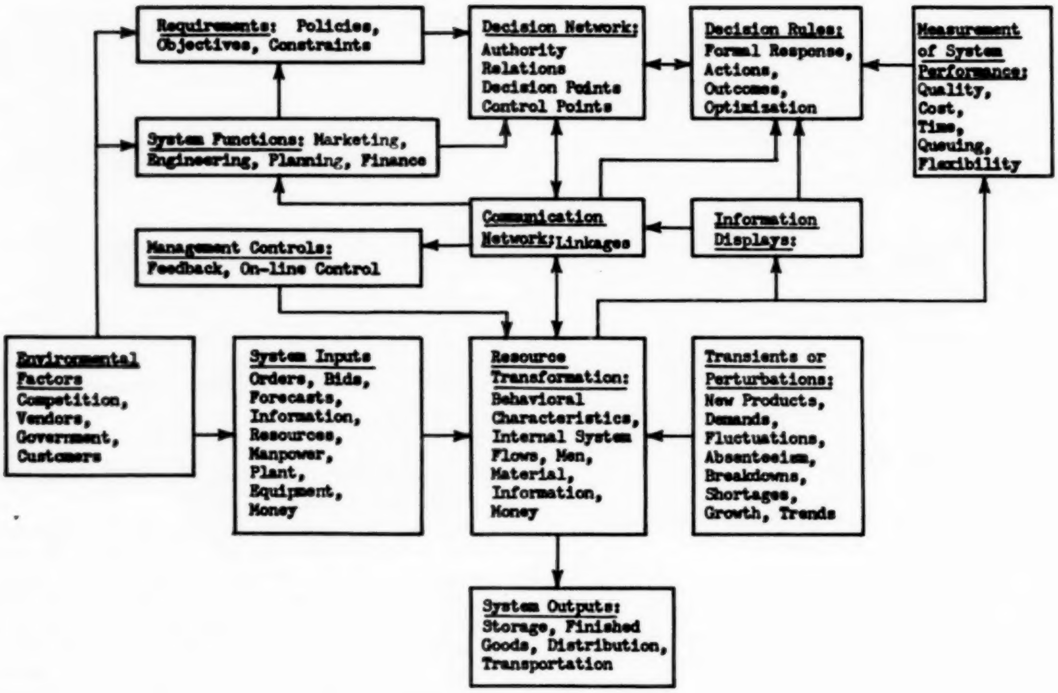

Requirements: Policies, Objectives, Constraints
Decision Network: Authority Relations Decision Points Control Points
Decision Rules: Formal Response, Actions, Outcomes, Optimization
Measurement of System Performance: Quality, Cost, Time, Queuing, Flexibility
System Functions: Marketing, Engineering, Planning, Finance
Communication Network: Linkages
Information Displays:
Management Controls: Feedback, On-line Control
Environmental Factors Competition, Vendors, Government, Customers
System Inputs Orders, Bids, Forecasts, Information, Resources, Manpower, Plant, Equipment, Money
Resource Transformation: Behavioral Characteristics, Internal System Flows, Men, Material, Information, Money
Transients or Perturbations: New Products, Demands, Fluctuations, Absenteeism, Breakdowns, Shortages, Growth, Trends
System Outputs: Storage, Finished Goods, Distribution, Transportation

Fig. 5 Activities and Functions of a Business System

To model the total business system, each of the boxes shown in Figure 5 would require considerable elaboration.

1. The Decision Network

Modeling a decision network is based on the ability to identify the points within the system where decisions are made. The kinds and number of decisions at each point, along with an explicit formulation of decision rules and information required for the decisions, is also needed. In a sense, the decision rules govern system behavior, thus providing an important aspect of any experimentation.

Since computer simulation is used to trace the change in the variables across a time domain, the decision rules can be made functions of the state of the variable rather than using expected values. In this respect simulation differs from dynamic programming or gaming strategies which depend on statistical estimates as the basis for optimization. Forcing functions, which trigger the decision rules, must also be specified and are related to information flow in the system.

2. Authority-Communication Network

In order to experiment with organizational considerations, authority relationships must be explicitly specified. Thus, priority factors or probability of success in implementing decisions can be made dependent upon the organizational level In view of the relation of information to the organization, the communication network defines key positions and, often, implied authority. An important consideration, then, is the possible distortion in information as it is transmitted through the various organizational levels. Distortion is produced by introducing synthetic noise or errors in the model.

The means of establishing alternate communication linkages or flexible flow is an important aspect of the modeling. Programming considerations are significant in that changing the information flow affects the basic structure of a model. A related problem is developing an effective means of characterizing the information content needed for decision criteria. The measurement of system behavior would include the density of information flow, queuing effects, and flow rates.

3. Measurement of System Performance

A major factor favoring the use of computer simulation is the capability of providing measures directly related to the system activities rather than indirect measures. The computer can continuously record the changes in system performance and thereby consider subsystem vs total system output, effect of aggregation on sensitivity of control, and the relationship between the system response and frequencies of reporting. In today's control systems, the exception principle is widely used since filing and summarization of information is difficult and expensive. However, with mechanical aids, measurement can be made to match the requirements more closely. In addition, accuracy in the data and speed of reporting can be greatly improved.

The computer can provide statistical analyses of the data, such as variance analysis, regression analysis, importance sampling, etc. Having this information, the experimenter is armed with the tools needed to evaluate and understand system behavior and response under alternative conditions. Undoubtedly, multiple or joint measures of system performance will be required rather than a single measure. Typically these include: cost, time, quality, reliability, flow rates, stability, queuing, etc. An analysis of the variables and their effect on system performance should reveal the ones which are critical to decision making. Using a joint measure of system performance and system variables, we anticipate the curve shown in Figure 6.

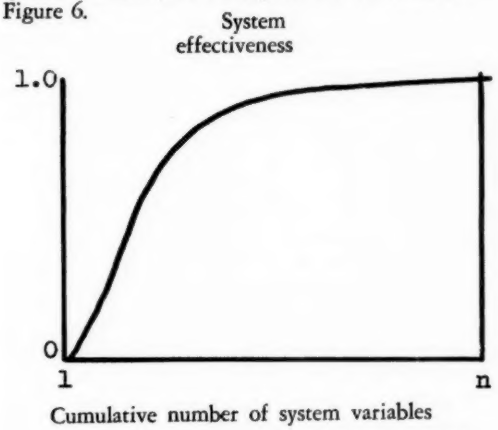


Figure 6—Relationship of Number of Variables to System Performance

Thus, knowing the critical system variables, it should be a simple task to design efficient methods of information flow and performance measurement for decision making and management control.

4. Management Controls

Management controls should be related to the total system design. Thus, a simulation model can be used to provide the insights and understanding of system behavior needed to obtain multi-functional or total control. The question of total system control has often been raised when considering centralized vs decentralized organization. Probably the most important aspect of control is the consideration of system objectives and constraints. It is in this area that formalized decision rules and decision criteria can provide a suitable control mechanism.

Since control is frequently related to feedback loops and correction factors, a number of considerations should be taken into account:

- Where should the control points be located in the system?
- What kind of information is required?
- What are the tolerable limits of deviation?
- How are decision rules used for corrective action?
- Can similar controls apply to steady state and transient conditions?
- Can sampling techniques be applied to provide critical damping?
- What are tolerable time lags in system response?
- Is on-line control preferable to a posteriori control?
- Can data enrichment substitute for the exception principle?

These and other considerations are amenable to study by a suitable computer model of a business system.

5. System Objectives and Requirements

In studying the objectives and design requirements of a system, it is undoubtedly best to start with the system constraints. The capital structure, resources, industry position, type of ownership, product and market stability all effect the system design. In a sense, the organizational structure, along with policy considerations, provides managerial adaptation to the system.

A number of considerations which bear on this problem include:

- management authority and information structure
- basis for changes in planning
- relationship of system performance to resources
- specification of interdependencies among components
- basis for testing system design

Undoubtedly, with the advent of computers, using planned information and decision rules, the organizational structure of the system will be most susceptible to change.

V. MODELING THE PHYSICAL PROCESSES IN THE BUSINESS

To this point, the discussion has been primarily concerned with the more intangible aspects of the business system. Although this part of the problem is unquestionably the most difficult to model, it probably represents the major potential in the design of management control systems. In addition, there have been numerous reports concerned with simulation of physical problems. (3) However, a brief description of some of the considerations in modeling the tangible aspects of the business system appear in order.

1. System Functions and Components

The study of a total system requires an explicit description of the time dependencies among the components. After policies and objectives are established, the allocation of resources to assure joint optimization can be determined. The primary concern is the conversion of resources into goods and services. By determining appropriate strategies in relation to risks, it is possible to control rates of change of production, work force stabilization, growth rate, cost-pricing, response to demand, and the relation of income to investment.

Since system optimization involves many variables, it is necessary to consider the combinatorial effects. Simulation is a means for examining a large number of variables simultaneously. However, the solution is not unique, but provides an estimate of the distribution of expected system performance. Thus, although all the combinations could not possibly be enumerated, sampling results tend to form relatively stable and determinable distributions.

A related problem is transient or perturbation effects in the system. Machine breakdown, shortages, rejects, absenteeism, etc., can also be characterized in the model. By providing appropriate distributions, and using random-number generators for Monte Carlo sampling, the stochastic properties of the system can be readily studied.

2. Internal System Flows and Characteristics

Flows within the system can be separated into information flow (paperwork, reports, etc.), material flow, resource flow, and manpower flow. Each has its own characteristics and is therefore modeled differently.

Starting with information flow, the channels or network determines the destination of the information, and the transmission media determine the speed and message type. Information content is a function of the data, format, and timeliness. One experimental variable in simulation could be the testing of the effect of report format on decision making. Transformation, distortion, and errors should be included, as well as the queuing effects at the decision points in the system.

Material flow has received the most attention in simulation and operations research studies. Thus, a considerable body of literature exists which could provide the basis for modeling. Reorder rules, safety stocks, value analysis, collation studies, scheduling rules, and stocking policies have been well documented. There are a number of additional considerations which might also be of interest, such as surge effects, queuing effects, interdependence of component parts, transformation processes, work-in-process flow rates, and resource utilization.

Resource and manpower flow are more difficult to solve since factors external to a simulation model may have the major influence. Nonetheless, there are aspects of these factors which can be profitably studied. For example, what are the cash flow requirements in a marginally capitalized business? What is the relation between demand variation and capacity? How does capacity and capital requirements change with different products, number of shifts, skill and mobility of manpower? These and similar questions are readily susceptible to study via computer simulation.

The internal system, in addition to the basic flows, has a number of other characteristics. In particular, it is necessary to structure certain behavioral patterns such as:

- demand and shipping patterns
- value distribution among products
- learning-curve effects
- variability in man-machine performance
- various lead-time distributions

In addition, there are a number of other system functions which should be contained in a business model such as:

- customer related—sales, engineering, estimating
- vendor related—procurement, inventory
- system related—quality, budgets, inventory, cost
- resource transformation—manufacturing, tooling, equipment, manpower
- information flow—data processing, accounting, retrieval

Rather than attempt an exhaustive description of the physical characteristics of the internal system, the considerations discussed are intended to provide some measure of the complexity and difficulty in modeling the business system.

3. External Factors

There are a number of environmental considerations, as well as system inputs and outputs, which should also be taken into account in the modeling. The number and type of competitors, customer demands, vendor characteristics and legal or civic factors all should be specified in developing a computer model of a business. Furthermore, forecasting of demand, gaming strategies, competitive pricing, and advertising policies are, in effect, the control of system response to variable demand. Thus, for example, maintaining standby capacity in anticipation of orders, having a complete product line, or carrying large safety stock in inventory, are all means of response which are really control of the system.

From a total system viewpoint, the availability of cash affects the above considerations; that is, carrying large inventories may determine the plant capacity required or the advertising budget. In this sense, the cash flow permeates all aspects of system behavior and thus affects control. Similar considerations enter into the make or buy question, material and tooling purchases, employment stabilization, etc. It is an explicit treatment of the many interdependencies which hopefully can provide the basis for total system control.

VI. CONCLUSION

The modeling of a total business system which incorporates the many considerations discussed, would undoubtedly involve numerous details. Thus, where possible, transfer functions or aggregations should be used rather than the precise flows or system characteristics. Not only does aggregation provide considerable savings in modeling, but, often more significantly, it helps reduce the size and complexity of a computer program. The modeling is, after all, designed to answer given questions or explore new areas and, therefore, should be governed by these considerations. Although the research results are dependent upon the adequacy of the model, it should be kept in mind that a model is still only a vehicle—a means toward an end, not an end in itself.

It cannot be overemphasized that these simulation techniques and data-processing equipment are tools—created, used, and controlled by man. This has been very forcefully stated by E. B. Arbuckle (4), Dean, Graduate School of Business, Stanford University:

"Machines will never replace man as tomorrow's managers. In fact he will have to be a broader, more competent and more unusual man than ever before. He will need: A deeper appreciation of the effect and application of technology and mathematics. A broader understanding of the social and political environment in which business operates. A flexible analytic mind receptive to change and adaptation and the habitual skill of self learning. A scale of values that admits that production is not an end in itself, but is a means to the elevation of man to higher levels of life and service."

REFERENCES

(1) LEAVITT, H. J., WHISLER, T. L., "Management in the 1980's," *Harvard Business Review,* Nov.-Dec., 1958.

(2) MALCOLM, D. G., "Real-Time Management Control in a Large-Scale Man-Machine System," System Development Corporation, Paper SP-90, July 26, 1959.

(3) MALCOLM, D. G., "A Bibliography on the Use of Simulation in Management Analysis," System Development Corporation, Paper SP-126, November 10, 1959.

(4) ARBUCKLE, E. B., *California Management Review,* Fall, 1959.

Chief Industrial Engineers' Symposium

Session I

What The Operating Departments Expect From Industrial Engineering

MODERATOR
ROY COLEMAN

PANELISTS
JULIAN T. McKINNON
CONRAD KUNZE
CHARLES O. HOLLINGSHEAD
R. W. UPDEGRAFF

An ancient Greek philosopher became famous by coining the phrase "Hard it is to be good". The phrase still has meaning in our modern industrial society, particularly in reference to the role of the industrial engineer. In industry the industrial engineer must approach his job as a professional. He must not be a yes man to top management, nor the complaint department for operating supervisors. Meeting the needs of management and the operating departments is a continuous challenge. To keep his program in balance a Chief Industrial Engineer should continuously try to determine what the operating departments expect from his engineers.

MR. ROY COLEMAN

MODERATOR

Mr. Coleman is a graduate of Texas A & M in the field of Industrial Engineering. He has been associated with several national concerns and served in executive capacities in Engineering, Operating and Finance. Today he is the President of Worth Chemical Products Co.

MR. JULIAN T. McKINNON

PANELIST

Mr. Julian T. McKinnon received his B S degree in chemical engineering from the University of Alabama. Ever since his graduation he has been associated with Proctor & Gamble Company. He has served in several capacities with this company and is currently Plant Manager of their Dallas plant.

MR. CONRAD KUNZE

PANELIST

Mr. Conrad Kunze attended Stamford University. He began his career in the Lumber and Mining business. In 1941 he became associated with the Northrup Aviation Company and since that time has held various executive positions with that company and later with Convair. Today he is Assistant Division Manager of Operations in Convair's San Diego Division.

MR. CHARLES O. HOLLINGSHEAD

PANELIST

Mr. Charles O. Hollingshead did undergraduate work at Oklahoma State University and his graduate study at the University of Pittsburgh and University of Colorado. He began his career in the electrical manufacturing field, and became Supervisor of Industrial Engineering at the Shawnee plant of Sylvania Electric Products Company, Inc. In 1958 he became associated with the Martin Company and today is the Assistant Manager of their Engineering Support Department.

MR. RALPH W. UPDEGRAFF

PANELIST

Mr. Ralph W. Updegraff is General Factory Manager at the Akron plant of the Timken Company. He is a graduate of Ohio Wesleyan and has had experience with several companies in the field of Industrial Engineering. He has been with Timken since 1948 and was their Chief Industrial Engineer prior to his present assignment.

Chief Industrial Engineers' Symposium

Session II

Measuring Industrial Engineering Performance

MODERATOR
GEORGE D. BOESCH

PANELISTS
JOHN B. LATHROP
G. X. REED
GEORGE B. TIMS, JR.

No industrial engineering program is complete unless it provides a means of measuring its own effectiveness. The performance of an industrial engineering department is the direct responsibility of the Chief Engineer. There seems to be no question as to whether or not this performance should be measured, but there is a question as to how often the measurement should be made. Who should set the criterion for performance, the Chief Industrial Engineer or Top Management? Developing information for measuring industrial engineering performance has in the past been a major problem. There is no doubt but this is a field requiring additional research.

MR. GEORGE D. BOESCH

MODERATOR

Mr. George D. Boesch received his B S degree in industrial engineering from Texas A & M. He started his career in the field of motion and timestudy at Montgomery Ward and Company. He has been associated with the Convair Division of General Dynamics since 1951. He has had various industrial engineering experiences with that company and today is Supervisor of Assembly Methods.

MR. JOHN B. LATHROP

PANELIST

Mr. John B. Lathrop received his degree in Mathematics from George Washington University. He has had varied technical and business experience. He has served in he actuarial field and during the war was active in government Operations Research Group. Since 1955 he has been with the Operations Research Division of Lockheed Burbank plant.

MR. G. X. REED

PANELIST

Mr. G. X. Reed is a graduate of Purdue University with a degree in Mechanical Engineering. He has been with Proctor and Gamble since his graduation in 1949. He has held various engineering assignments with that company and today is head of Industrial Engineering at the Dallas plant.

PROFESSOR GEORGE TIMS

PANELIST

Professor George Tims is head of the Department of Industrial Engineering at the Lamar State College of Technology. He did undergraduate and graduate work in the field of Industrial Engineering at Oklahoma State University. He has been active in that field of engineering both in industry and education.

section 29

THE ECONOMIC PROBLEMS OF THE SIXTIES

by ARTHUR A. SMITH
Vice-President
FIRST NATIONAL BANK OF DALLAS

Dr. Smith is nationally known as a Lecturer in the field of Economics. He has had a distinguished career in the academic field, where among other positions he was head of the Economic Department of Southern Methodist University. In addition he has been a business and research consultant for various national firms and arbitrator in labor-managemene disputes. Dr Smith received his B.S. degree from Missouri State College, his Master's degree from Peabody College and his Ph.D. from Vanderbilt University.

section 30

ENGINEERING ASTIGMATISM

by JOHN D. COLEMAN
Supervisor

FIELD TESTS
FRIGIDAIRE DIVISION
GENERAL MOTORS CORPORATION

Mr. John D. Coleman is one of the nation's best known Engineers. He has held important offices and positions of honor in an impressive number of professional and civic organizations. He has served both as President of the American Institute of Industrial Engineers and the National Society of Professional Engineers.

He is a graduate of West Virginia University with a B.S. degree in Chemical Engineering, and a member of Phi Lambda Upsilon.

Mr. Coleman has had many important engineering positions with nationally known companies. At the present time his is Supervisor of Field Tests in the Production Engineering Division of Frigidaire.

ENGINEERING ASTIGMATISM

by JOHN D. COLEMAN

Field Test, Frigidaire Division, General Motors Corporation

GILBERT Chesterton tells the whimsical story of the architect who was annoyed at the sight of an ugly house which he passed every day on his way to the office. To escape the irritating sight, he bought the house and moved into it. By living in it he could thus avoid looking at it.

Let's step outside of our "house of engineering" and honestly appraise our edifice and ourselves remembering that while we no doubt share most of our shortcomings in vision with our brothers in other walks of life we are members of an honored profession with responsibilities of a higher order.

When we examine ourselves and our brothers in the profession we all too frequently observe a characteristic that might be called "astigmatic perspective". This is usually manifested by an inability to see himself, his work, his community, or his profession in clear perspective.

For convenience we can break down this visual defect into two logical areas in order to facilitate further examination, namely 'technical and professional astigmatism'. Like most things in life there are both good and bad features of these characteristics which we should examine impartially.

Technical Astigmatism

1. Preoccupation with technical data, instrumentation, etc., without clear concept or regard for end product.
2. Tendency to use technical language or, worse yet, 'gobble-de-gook' which is unintelligable to laymen to whom we would like to sell our ideas or make a good impression.
3. Lack of perception of the bearing our work has on the rest of the project.
4. Inability to relate the work of the engineering group to other essential operations in the enterprise.
5. Poor or non-existent public relations with other parts of the operation.
6. No clear appreciation or thought for the social significance of work we perform.
7. Permits unfailing concentration on individual project or problem.

Professional Astigmatism

1. Carelessness in personal appearance.
2. Sloppy grammar in speech and written reports.
3. Absence of or little feeling of professional responsibility.
4. Little knowledge of or interest in the problems of the engineering profession.
5. No interest in broadening either education or interests outside of the technical field.
6. Viewpoint on problems common to the profession influenced unduly by technical organization affiliation.
7. Interest in profession, if any, diminishes or vanishes upon assuming supervisory or managerial duties.
8. Disinterest in and-or unwillingness to contribute time and talent to community enterprises where his training and experience qualifies him.
9. Does not see value or need for a professional engineering organization to represent the viewpoint of engineers in all branches and specialties.

Perhaps you have known someone who displays some of these failings and I am sure most of us could match some of these characteristics.

We might well say, "So what?" That's just typical of engineers and why should we worry?" Candidly, it won't mean anything if we are not interested in our professional status but we cannot long ignore this 'astigmatic perspective' for it can mean loss by default of any claim we now have as members of a profession. As a recent commentator stated, "We can't repair the past—but we don't have to repeat it."

Our profession today is on the highest plane in its history and the contributions of the engineer are better known and appreciated than ever before. We should remember however that this can change as the German proverb stated, "Whatever is in the sun either ripens or withers."

The Industrial Engineer should be in the best position to develop a professional perspective for his education is supposed to train him to look at the whole project, undertaking or organization. Should he not be in the forefront then showing the way to his brother engineers with less astigmatism and with a clear cut picture of his place in his organization and society and the contributions he can and should make as a professional.

Burton Hillis of Better Homes and Gardens stated the proper attitude for the professional man when he said, "The more you give and do, the more you have and are."

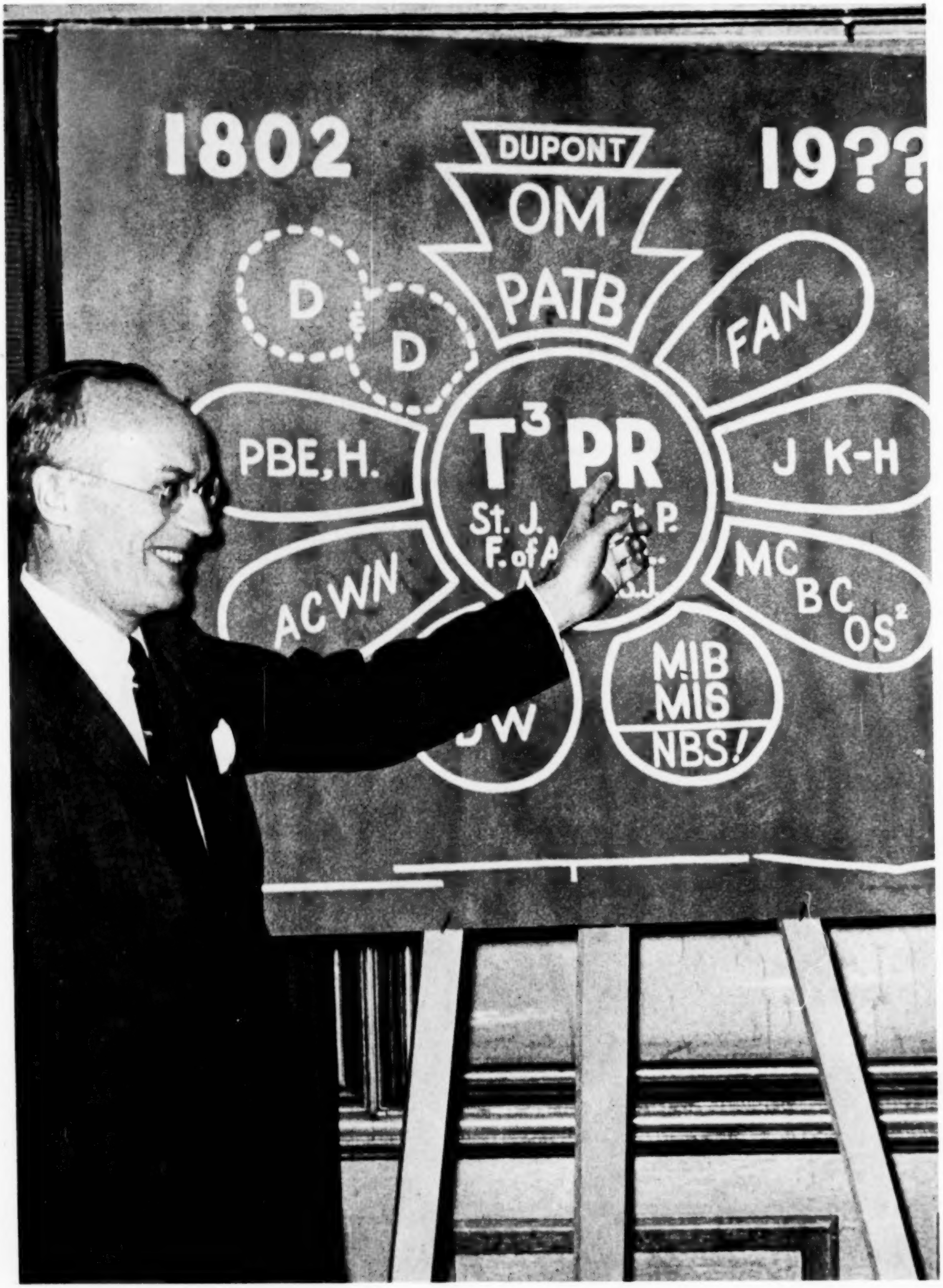
PATTERN FOR SUCCESS

by JAMES Q. duPONT
Administrative Assistant

E. I. duPONT deNEMOURS CO., INC.

Mr. duPont was born in 1902, the eldest of six children of the late Evan Morgan and Helen Quinn duPont. He is a great-great-grandson of E.I. duPont deNemours, founder of the Du Pont Company.

In 1926 he graduated from M.I.T. with a degree in Electrical Engineering. Mr. duPont held various positions in engineering and management with various companies before joining the du Pont Company. He has been active with the du Pont Company in its various atomic energy projects and was responsible for their work at Oak Ridge and Hanford Engineer Works in the State of Washington. In 1948 he was selected by Edward R. Murrow to participate in the radio feature "This I Believe". Since that time he has been active in the public relations field for the du Pont Company.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PATTERN FOR SUCCESS

by James Q. Du Pont

Administrative Assistant, Public Relations Department,
E. I. du Pont de Nemours & Company

BELIEVE me, it's a privilege and an honor to have this opportunity to talk to your Eleventh Annual National A. I. I. E. Conference today and to have this chance to try and box this business compass which has guided du Pont from a little one-man show in 1802 to our present size and nature today.

Now about this chart of mine, this "compass," I would like to give any possible future readers of your proceedings a mental guide or picture. Consider a chart which looks somewhat like a clock, excepting that instead of having the usual twelve numerals it has eight circles around the circumference, a hub at the center, and a keystone-shaped block at top-center where 12 o'clock would normally be found. So visualize, if you will, this business compass with true North at 12 o'clock and a hub in the middle. I'm going to "box" this compass, but before I start to do so, I should say three things about the compass for your better understanding and use thereof.

First, it is simple! You know, simple like the Ten Commandments! Easy to memorize, easy to rattle off, or recite. But if you are a sinner, like I am sometimes, oh, how hard to hold all Ten Commandments "on the hook" all the time! And it seems to me that the engineer's great problem, and the businessman's great problem, and almost anybody's problem in using this pattern for success is not so much this point or that point or any other, but the eternal balance of these ten principles. So don't be fooled by its simplicity.

Suggestion two about this little compass is this. It may be regarded from three points of view. First, as a guide to top management, if such you are or aspire to be. Second, it may be used as a yardstick to compare your company or your employer with our du Pont "standard" if you do not have a better standard and, of course, I know that well you may. But if you don't, then here is your chance. Then, third, some of you may use this, if you care to, as a guide to individual success. How can this pattern for success help you in an individual way, Jack Jones, or Bill Smith, better to succeed? So don't forget now, take your own point of view. The choice is yours.

Finally, here is my last comment about this compass, this du Pont pattern for success, which I am going to describe. Chairmen across the nation are all alike, and your own was no exception today. He announced this as "Pattern for Success." Well, this is not the whole title. It should be called "Pattern for Success in a Mere Material Way." Much as I almost love the Du Pont Company, I realize it is just spit in the ocean or a grain of sand on the beach compared with the more eternal and spiritual values in your life and in mine. I just wanted to straighten out this point. Don't think that we are parading this as "Pattern for Success"—period. It is not nearly as important as that. But I do hope it may help you somehow.

Now let us box this compass, and I'm going to start at what would be 1 o'clock on the chart. I have there the initials F. A. N. These stand for Fill A Need. In other words, make a product or sell a service for which you are convinced there is a need. Sounds simple, doesn't it? But don't get caught like the young inventor in Detroit shortly after the turn of this century. He decided to risk his life's savings and his family's money on a brave little enterprise to fill a need. It was called something like the Detroit Improved Buggy-Whip Holder Company, and there was a great need in America then for improved buggy-whip holders. But this young man failed miserably. He did not take into account that Mr. Selden, Mr. Maxwell, Mr. Winton, Mr. Henry Ford, and others were playing around with you know what. The big need disappeared almost overnight for buggy-whip holders and a lot of other associated items. You should never be fooled that way. You've got to make sure that the need will continue or get out while the getting is good!

Now certainly there is a crying need for engineers in the world today. Although electronics and space-age mechanical engineers now seem to have an edge on most of the other classes of our profession, I have it on pretty seasoned authority that "operations research" and associated endeavors do cry out for topnotch industrial engineers. The radio, the press, the technical papers are full of articles about the need for young college and primary students to get into technical fields. But over and beyond their technical abilities, it seems to me, there is something else engineers have that is desperately needed in the world today, and that is honesty—honesty. Now I don't mean to imply for a moment that the engineering profession has a monopoly on honesty, of course not! But I'm sure that one of the almost inescapable results of good engineering training is a sort of clear-eyed, rock-solid, built-in honesty. Young engineers quickly learn that it is impossible to stretch a slide rule to make the answer come out like someone wants it. And they learn that they cannot design a bridge with a safety factor, for instance, that's less than par just because some political or other pressure wishes to cut down on costs. Not at all. They can't do that without having to face the awful price of a bridge collapse or failure. So most engineers do have that calm and sure honesty which, I think, is so extra important in our world situation today.

At point two on our diagram, we have the initials J. K-H. These stand for the Job Know-How to fill the needs in question. You certainly realize that you must have job know-how to do well whatever work you are now doing. Incidentally, it appears to me that these very well organized and complete annual A. I. I. E.

conferences are one ideal source of good new job-knowledge. In the Du Pont Company we have the job know-how to produce many chemical products which help in your living today. Starting way back in 1802, my great-great-grandfather, the founder of our company, was lucky enough to have some very fine chemical job know-how which he picked up under the celebrated Lavoisier.

Oh, yes, and while we are on this point, don't neglect the old people in your organization wherever you are. Don't neglect the older heads around you. Now I know that some of you younger engineers may say, "Now wait a minute, du Pont, wait a minute! Much that's stored in my old supervisor's head is obsolete and out-of-date and inaccurate." Well, I know that too. But on the other hand, much that is buried in the older heads around you is just as fine, just as virile and worthwhile as it was the instant it was conceived in what I like to call "that fabulous hunk of gray tissue" which The Great Designer has placed within our skulls. And so I say to the younger people, "Go to the older engineers in your organization and pump their brains for all they're worth. See if you can't find some of the information that is hidden there—priceless job know-how."

"Read the best books on your subject for more know-how, no matter what sort of engineering is your love. Incidentally, the best books are usually, although not always, the hardest. Go back to first principles about your job. Get down to basic facts every possible time." So much for point two—Job Know-How.

Now next on our chart we have the initials M. C. These stand for Meet Competition. Meet and beat competition if you can. Go out with your own job know-how, and armed with as much information about your competitor's team as you can find, meet him fairly and squarely on the "football field" of business. Try to make the score as big as possible in your favor. Meet competition! Outsell and outservice the other fellow, the other company, the other organization.

At point four we have the initials M. I. B.-M. I. S. I could have put just an "I" for this point four. "I" would stand for Improve, Improve endlessly. But my chart says M. I. B.-M. I. S., and this stands for Make It Better, Make It Safer!—another way of saying "Improve."

I like the expression, "Make It Better, Make It Safer, Make It Safer, Make It Better." It sometimes reminds me of two squirrels in a cage. A Mama and a Papa squirrel chasing each other around the wheel, working and playing and producing happily together. It's almost impossible to make a product better without making it safer, or vice versa. So we say, "Make It Better, Make It Safer!" Never be satisfied with your own best work. Certainly this "passion for improvement" is one of the most important objectives of industrial engineering as I know it. And the principle applies to industrial engineers just as much as they try to apply it to their engineering. To compete effectively today you need to be more than an industrial engineer—you must be a topnotch one as you may remember me saying under point one of this "Pattern for Success."

Point five comes next. About 7 o'clock on the diagram, I have T. and E. These stand for Thrift and Economy in du Pont's pattern for success. Don't waste anything. Even if doing these things like filling needs with the job know-how and the competitive spirit and research that I've just talked about, you find yourself very successful as a company or an individual, don't get a swelled head. Don't gild the lily! Don't, as the girls sometimes say, "Don't chi-chi up the works." Don't chromeplate the brass fire extinguishers (unless it's chemically indicated). Save something, save everything! No, I mean, don't *waste* anything. This is an old, old policy of ours that came about, I think, chiefly due to Du Pont's awful early struggle with debt. In our early days, Du Pont had a crying need for working capital, just as almost any small business starting to grow usually needs working capital desperately. This point of ours fits like a glove another one of your profession's objectives, i. e., prevent or eliminate waste. About the only thing I might add to some of you younger industrial engineers is that the crying need for working capital sometimes makes the powers-that-be "sort of deaf" to your pleas for an investment to eliminate waste. You'll have to figure out special, very diplomatic ways to make him even hear you.

And now we are up to point six. This is a tough one! On the surface, it is a dry one. Do you see what it says on the chart here? It says A. C. W. N.—this stands for Additional Capital When Needed. Putting this another way, so act, so behave, yes, so be, that you can borrow additional money when you need it. Some examples: your family has triplets coming up, or your house has burned down, or your place of business has been ruined by fire or flood and you need to borrow more money. We feel that it is most important to have so been in the past that you can borrow more money anytime you need it. Bankers assure me that I am dead right on this one.

Now I know that bankers realize that sales forecasts are important. Engineering surveys, market research, all of these things are important, of course. But in a large business or in a small one, it is not primarily what your forecasts say you are going to be, or what your own hopes practically insist that you are going to be, which impress the bankers. No, no! The question that the banker is silently asking himself as you beat on his door for more money is this, "How has this man, or woman, this family, this company, behaved? How has it acted?" Yes, like an old backwoods preacher once so beautifully put it to me, "How has you so been?" You know, in that awful past perfect tense of the verb "to be" when there is nothing you can do about it now! It's a matter of reputation. You can lose it overnight, by the way, but you can't gain it so quickly.

So this is what we mean by Du Pont's point six, A. C. W. N., in our "Pattern for Success." I wish I had more time, but I simply do not, to tell you a hair-raising story about 1818 when our Du Pont plant, the old powder plant, blew up almost completely. Sometime again maybe I shall be invited back here or maybe you will see our Du Pont motion picture, "The Du Pont Story," and you'll see what happened in 1818 and why this rule, this point six, "So behave that you can borrow more money," saved the Du Pont Company at that time, as it has at several other critical periods in our past.

Point seven is easy. We'll make time on this. Its symbols on my chart are E. P. B.-H. These stand for Earnings Plowed Back, Heavily. In other words, this says, "Save something for a rainy day." If your family or your company has had an extra good year, don't go overboard and buy your wife a fur coat, a new bedroom suite, and a color television. Get her, say, two out of three of these items but don't give her all three! Save something for improving the roof in case it develops a leak, or the foundations if they start to sag.

If you have a company and you make a wonderful profit in a year, a lot of profit, don't dish it all out as a too-big dividend, or as a too-big remuneration to the employees, or as a too-big price cut to that most important fellow of all, the customer! No, treat all of these factors generously but hold something back for a rainy day, for the good of the business, for the good of the employees, for the good of the stockholders, and for the good of the customer. In other words, retain a nest egg of earnings if you can.

Now we are around to point eight, D. and D., of our "Pattern for Success." It would be at about 11 o'clock if you could see my diagram. Point eight is the only one, by the way, of Du Pont's ten principles for business success which was not practiced by the founder, E. I. du Pont, right from the beginning. This point was adopted early in this the Twentieth Century. It started about 1909 or 1910, budded some in the teens, and then really blossomed in the 20's. The principle is Diversification. In other words, make many products, not just one. Put your eggs in more than one basket, especially if your supply of eggs grows large.

Now I know that many of you listening to this talk are going to say, "Now wait a minute, du Pont! One can be a great success in just one line, such as a doctor, a lawyer, a musician, or an engineer, specializing in just one thing." Sure you can. And you can make just one product—pencils, for instance, or chairs, or tables, and be a howling success. Of course you can, but we simply say that, in general, if you get big (Du Pont is big and I am proud of it), it pays, usually, to diversify and to make many products, not just a few.

This diversifying is true about a family, too, or an individual. Take myself, I sometimes wake up in a cold sweat at 3 or 4 in the morning and think, "Good Lord! What if I get chronic laryngitis or maybe even some throat trouble more serious from these wonderful and awful cigarettes? What would I do?" I now make my living almost entirely from speaking, whether you believe it or not. What could I do? Well, I am diversified a bit. I have a couple of ideas up my right sleeve. For instance, I might help others write speeches. I could help others prepare their talks in several ways—perhaps coach them with delivery, etc. And then I have a couple of other ideas up my left sleeve that I haven't even told my wife about and which I could use, I believe, if I lost my voice. And so, you see, I am ready to diversify as an individual. You might consider being ready to do this also.

However, don't make the sad mistake of getting so worried about losing your present job or losing your present business that you spill the beans. Don't do that! But, in general, it pays for most of us to be able to diversify. In the Du Pont Company today we make 1200 different products and product lines. Think of that! Twelve Hundred instead of just one like old E. I. du Pont made in 1802. How amazed and proud he would be!

Suppose some competitor of ours, under a very aggressive research policy of his own (such as I have talked about in point four of this pattern) comes out with, say, some textile fiber that makes one of our textile fibers obsolete (God forbid, but it could happen). If he does, the Du Pont Company will be pretty sad, but it won't turn over on its back and die! It will go right on making and selling those 1199 other products, plus some new ones just around the corner.

Now this brings us to the second half of point eight and that is Departmentalization. This suggests that when you do make and-or sell many, many things (and get pretty big) you have to rearrange your organization of employees. You have to say to Joe and Bill, "Now, this textile fiber department is your baby." And to other capable fellows in chemicals, paints, etc., "This is your baby. Run it as you see fit. You have a white ticket to run this show, with only a few strings attached."

In 1921 the Du Pont Company almost died, believe it or not, and not of old age like we almost did in 1902. (Ask me back again sometime and I'll tell you that story.) In 1921 the Du Pont Company, very, very successful, almost died of "corporate neurosis" because we hadn't departmentalized. Irenee du Pont "saved the day" that year and broke us down into the departmentalized organization we now are. As some of you may know, we now consist of twelve manufacturing or industrial departments as we call them, and thirteen auxiliary or staff departments.

Let us look now at the hub on my chart and we are almost finished with this story. At the center of my diagram, we have the initials T3. P. R. I'll say that again. T cubed P. R. In other words, T. T. T. P. R. This stands for Try To Treat People Right, and don't underrate that little 3-letter word T-R-Y!

I used to write R. T. P. for Right Treatment of People. Then it dawned on me that it was presumptuous, even wrong, to say, or imply that the Du Pont Company always treats people right. Our company doesn't always treat its people right, believe me. It makes mistakes like any other human organization. But I think the important thing here is that the Du Pont Company, from Walter S. Carpenter, Jr., chairman of our board, and Crawford Greenewalt, president, right down to the first-line supervisor in our newest plant, tries hard and everlastingly to treat its people right.

While I don't want here to imply that Du Pont has a patent-right on this T3. P. R. formula, I can assure you it is, and always has been, our cardinal principle. And it is this knowing that your boss, in general, is trying to treat you right that makes you almost, like I said at the outset, love the Du Pont Company—at least I do.

And now to point ten, the last, the keystone on the diagram. Its symbols are O. M. and P. A. T. B., Owner Management and Personal Attention To Business. I suspect there is no substitute for this double-barrelled principle. We know that managers who are also owners have that wonderful proprietary interest so difficult to be had in almost any other way. We think there's nothing to be ashamed of about this and we think it's right and good. We nurture this principle with our bonus system which usually works to give the higher managers a considerable stock interest in the business as their years roll on.

Finally, P. A. T. B., Personal Attention To Business. the last half of this last point, and then I'm done. It means, among many other things, that you will take many calculated risks you would never take if you were not personally on the scene and "in the game."

We think it has been the taking of big calculated risks that has made the United States what it is today and made the Du Pont Company likewise, and I think if your profession of industrial engineering is to continue its important place in the scheme of life today, and to reach up and attain those new standards of proficiency and usefulness which are so obviously foretold by this great conference, then it will be because you, as individuals and as groups, will have had the courage to take big calculated risks in business, in education, in politics, and in every other field that really counts.

Thank you.

Senior Chapters

1. Columbus, Ohio
2. Dayton, Ohio
3. Pittsburgh, Pennsylvania
4. Jamshedpur, India
5. Metropolitan New York
6. Atlanta, Georgia
7. Cleveland, Ohio
8. Cincinnati, Ohio
9. Birmingham, Alabama
10. Dallas-Ft. Worth, Texas
11. East Tennessee
12. San Francisco-Oakland, Calif.
13. Syracuse, New York
14. Washington, D. C.
15. Tulsa, Oklahoma
16. St. Louis, Missouri
17. Tri-Cities, Tennessee
18. Louisville, Kentucky
19. Stark County, Ohio
20. Seattle, Washington
21. Winston-Salem, North Carolina
22. Houston, Texas
23. Los Angeles, California
24. Youngstown, Ohio
25. Chicago, Illinois
26. Savannah, Georgia
27. Jacksonville, Florida
28. Memphis, Tennessee
29. San Diego, California
30. Boston, Massachusetts
31. Philadelphia, Pennsylvania
32. Rocky Mountain, Colorado
33. Pensacola, Florida
34. Fort Wayne, Indiana
35. Central Indiana
36. Toledo, Ohio
37. Peninsula, California
38. Twin City, Minn. & Wis.
39. San Antonio, Texas
40. Miami, Florida
41. Baton Rouge, Louisiana
42. Baltimore, Maryland
43. Sacramento, California
44. Rochester, New York
45. Milwaukee, Wisconsin
46. Mississippi Valley, Ia. & Ill.
47. Detroit, Michigan
48. Southern Tier, New York
49. Niagara Frontier, New York
50. Great Salt Lake, Utah
51. Erie, Pennsylvania
52. Akron, Ohio
53. Calumet, Indiana
54. Chattanooga, Tennessee
55. Macon, Georgia
56. Wichita, Kansas
57. Oklahoma City, Oklahoma
58. Charleston-Huntington, W. Va.
59. Albuquerque Area, N. M.
60. East Texas
61. Metropolitan New Jersey
62. Merrimack Valley, N. H. & Mass.
63. Tri-State, New Hampshire
64. Middle Tennessee
65. Indianapolis, Indiana
66. Eastern North Carolina
67. Portland, Oregon
68. Worcester, Massachusetts
69. North Alabama
70. Central Arizona
71. Lancaster Area, Pennsylvania
72. York, Pennsylvania
73. Nashville, Tennessee
74. New Orleans, Louisiana
75. Central Connecticut
76. Mid-Hudson, New York
77. Lehigh Valley, Pennsylvania
78. San Gabriel Valley, California
79. Mobile, Alabama
80. Central Illinois
81. Western Virginia
82. Southwestern Connecticut
83. Western North Carolina
84. Central Arkansas
85. Mohawk Valley, New York
86. Long Island, New York
87. Southern Ontario, Canada
88. Evansville, Indiana
89. Susquehanna Valley, Penn.
90. Omaha, Nebraska
91. Florida West Coast
92. Kansas City
93. Northwest Georgia
94. Springfield, Massachusetts

95. Harrisburg Area, Pennsylvania
96. Binghamton, New York
97. Naugatuck Valley, Connecticut
98. Saginaw Valley, Michigan
99. Southeastern, Virginia
100. Wilmington, Delaware
101. Central, Virginia
102. Capital—Berkshire, N.Y., Mass., Vt.
103. Marion, Ohio
104. Central, Florida
105. Orange County, California

Student Chapters

University of Alabama
University of Arkansas
Bradley University
University of California
University of Southern California
Case Institute of Technology
Columbia University
University of Florida
Georgia Tech
University of Houston
Illinois Institute of Technology
Iowa State College
State University of Iowa
Johns Hopkins University
Lafayette College
Lamar State College of Technology, Texas
Lehigh University
University of Missouri
University of Minnesota
Montana State College
Newark College of Engineering
New York University (Day Division)
New York University (Evening Division)
North Carolina State College
Northeastern
Northwestern
Ohio State University
Oklahoma State University
Oregon State College
Pennsylvania State University
University of Pittsburgh
Purdue University
University of Rhode Island
Rutgers University
Stanford University
Syracuse University
University of Tennessee
A & M of Texas
Texas Tech
University of Utah
Virginia Polytechnic Institute
Washington University
Wayne State University
West Virginia University

American Institute of Industrial Engineers, Inc.

AMERICAN INSTITUTE OF INDUSTRIAL ENGI
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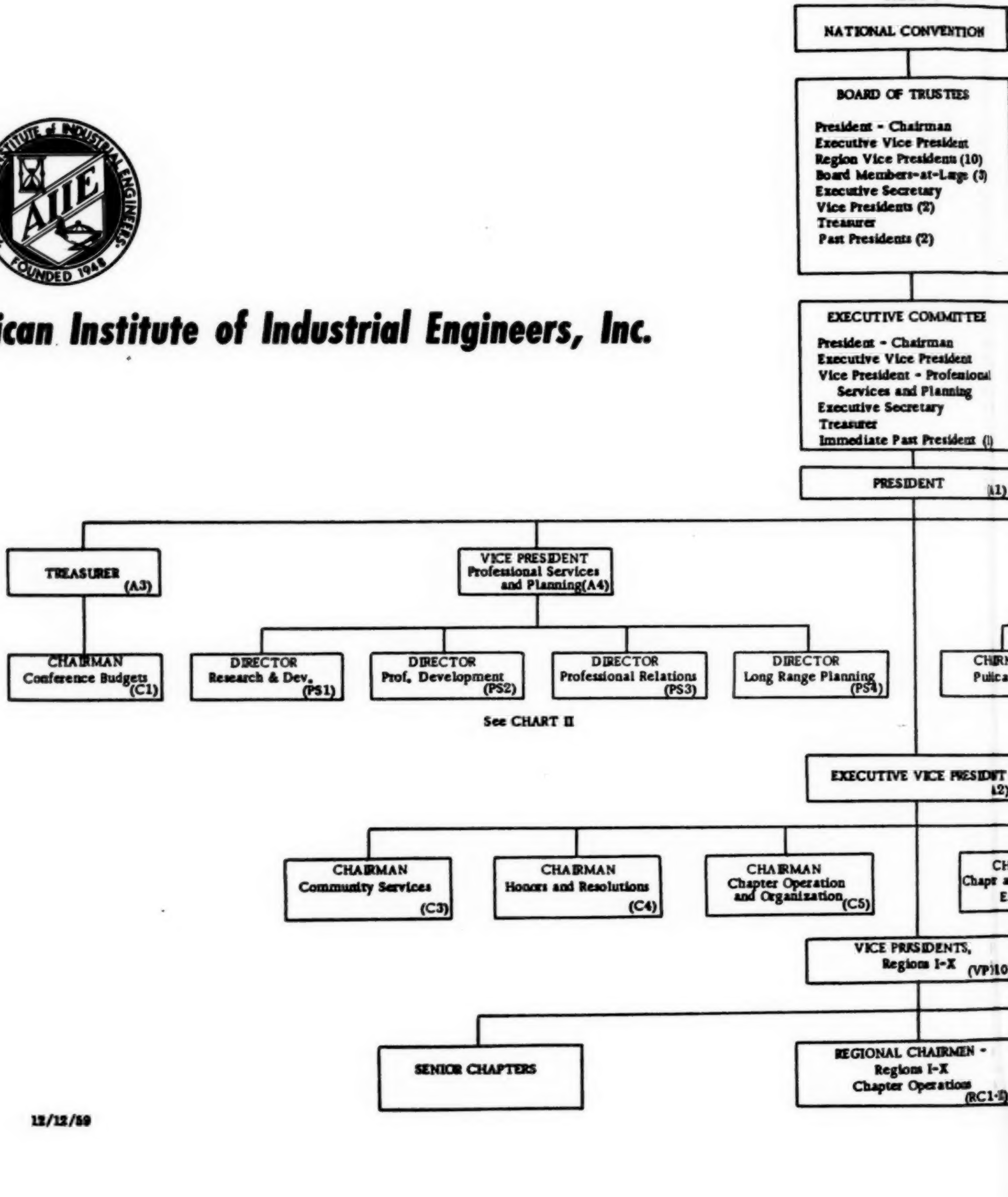
CHART I


NATIONAL CONVENTION
BOARD OF TRUSTEES
President - Chairman
Executive Vice President
Region Vice Presidents (10)
Board Members-at-Large (3)
Executive Secretary
Vice Presidents (2)
Treasurer
Past Presidents (2)
EXECUTIVE COMMITTEE
President - Chairman
Executive Vice President
Vice President - Professional Services and Planning
Executive Secretary
Treasurer
Immediate Past President (1)
PRESIDENT (A1)
TREASURER (A3)
VICE PRESIDENT Professional Services and Planning (A4)
CHAIRMAN Conference Budgets (C1)
DIRECTOR Research & Dev. (PS1)
DIRECTOR Prof. Development (PS2)
DIRECTOR Professional Relations (PS3)
DIRECTOR Long Range Planning (PS4)
CHAIRMAN Pulica
See CHART II
EXECUTIVE VICE PRESIDENT (A2)
CHAIRMAN Community Services (C3)
CHAIRMAN Honors and Resolutions (C4)
CHAIRMAN Chapter Operation and Organization (C5)
CH Chapt a E
VICE PRESIDENTS, Regions I-X (VP)10
SENIOR CHAPTERS
REGIONAL CHAIRMEN - Regions I-X Chapter Operations (RC1-

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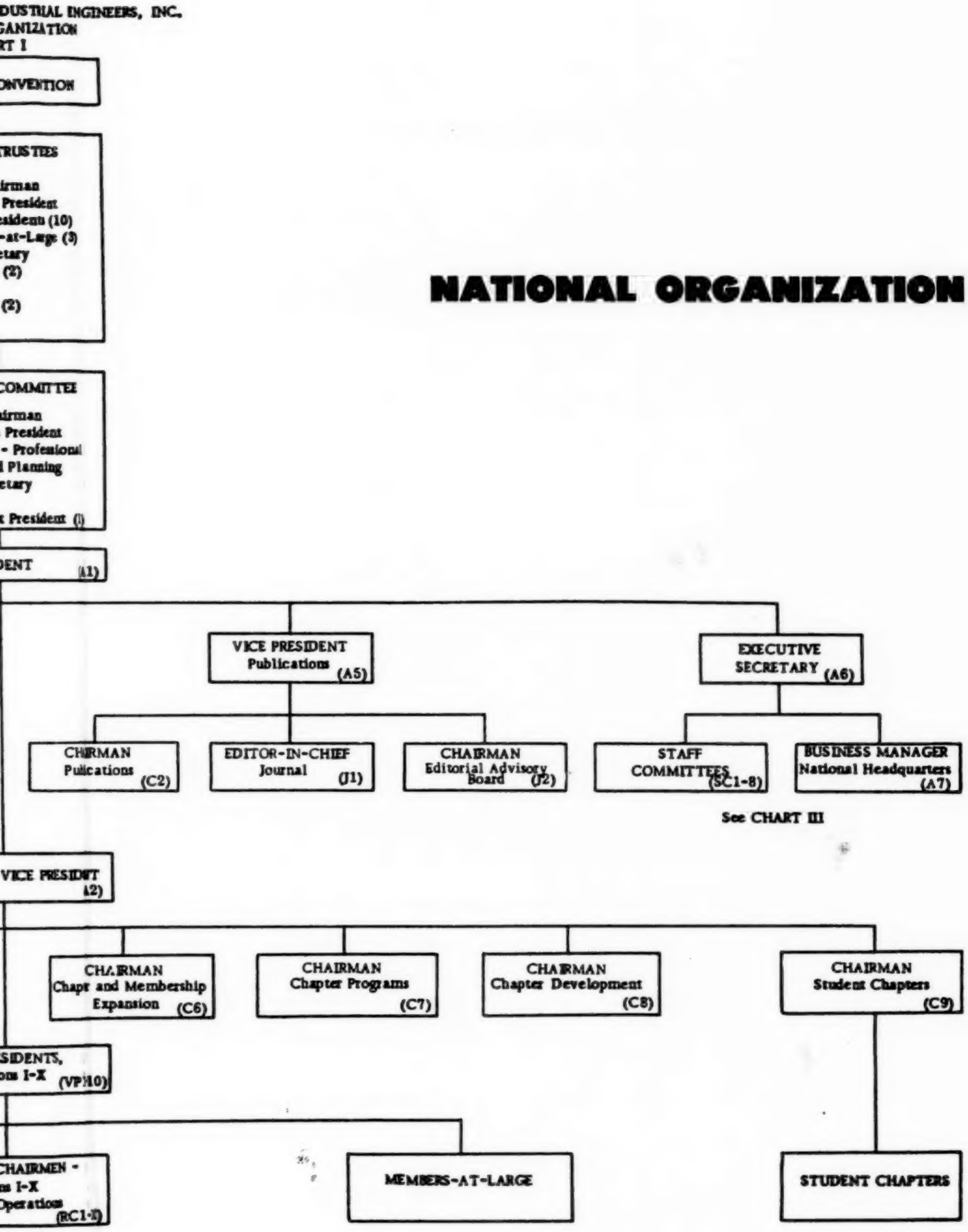
NATIONAL ORGANIZATION


DUSTRIAL ENGINEERS, INC.
GANIZATION
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DENT (A1)
VICE PRESIDENT Publications (A5)
EXECUTIVE SECRETARY (A6)
CHAIRMAN Pulications (C2)
EDITOR-IN-CHIEF Journal (J1)
CHAIRMAN Editorial Advisory Board (J2)
STAFF COMMITTEES (SC1-8)
BUSINESS MANAGER National Headquarters (A7)
See CHART III
VICE PRESIDENT (A2)
CHAIRMAN Chapt and Membership Expansion (C6)
CHAIRMAN Chapter Programs (C7)
CHAIRMAN Chapter Development (C8)
CHAIRMAN Student Chapters (C9)
SIDENTS, ons I-X (VP10)
CHAIRMEN - ns I-X Operations (RC1-1)
MEMBERS-AT-LARGE
STUDENT CHAPTERS